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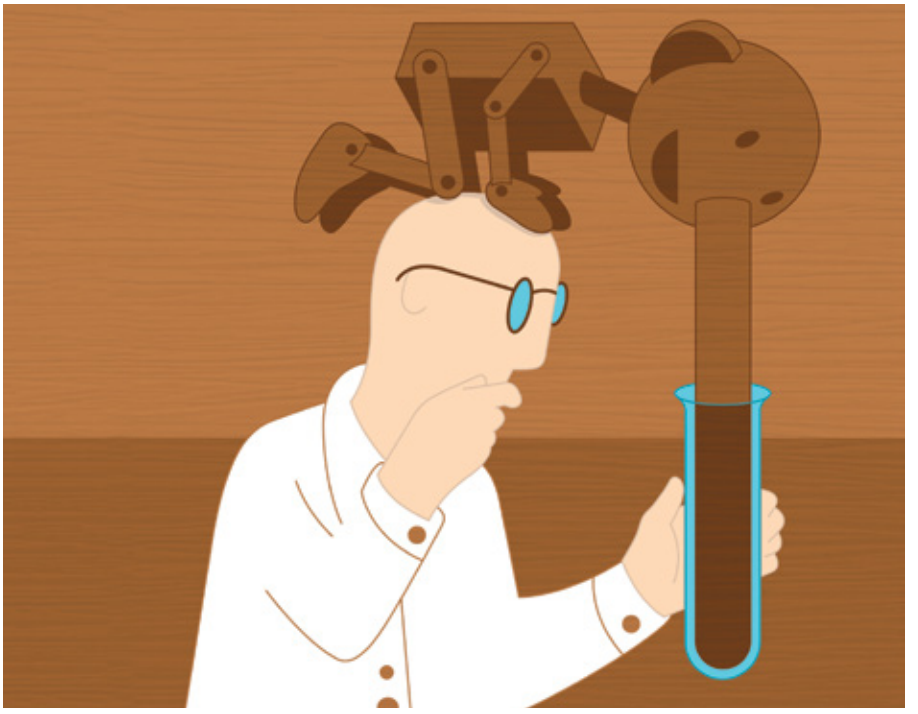

FROM THE EDITOR

Science Lights the Way

In 1998 British researcher Andrew Wakefield and his colleagues published a paper showing a link between the measles-mumps-rubella vaccine and the incidence of autism in children. During the following years the paper was exposed as an elaborate fraud and was retracted by the *Lancet,* the journal that published it. Dozens of follow-up studies have since shown zero connection between vaccines and autism.

That paper, though thoroughly discredited, started a public panic (with celebrity backing) and resulted in tragic outcomes: record low vaccination rates among children, outbreaks of measles in theme parks, resurgences of diseases once considered rare. Nearly half the American public believes in the vaccine-autism link or is unsure about it.

It is a case in which scientific evidence has struggled to convince. Sadly, this story is not unique in a political climate that disregards sound reasoning and widely accepted scientific fact. The era of post-truth is upon us, writes Kathleen Higgins on page 6, where there is no longer even an *expectation* of honesty from politicians and pundits alike.

Research shows that even in the face of valid facts, some people retreat to moral positions in their arguments (*page 112*). This avoidance tactic is the underpinning of bias and can dismantle reasonable discourse and critical thinking. As Troy Campbell and Justin Friesen write on page 14, "We have learned that bias is a disease and to fight it we need a healthy treatment of facts and education." Consider this issue a potent first dose. Inside is a collection of articles that present the science on some of the most contentious matters of our times: climate change, vaccines, genetically modified organisms, gun violence and creationism.

The canny reader will quickly notice a common theme. For each topic, there really is no debate where the science is concerned. Take climate change. A 2014 survey by the Pew Research Center and the American Association for the Advancement of Science found that nearly 90 percent of scientists were in agreement that a warming planet was a direct result of human activity (*page 46*). Likewise for the research on firearms: the majority of evidence clearly shows that more guns lead to more gun violence (*page 62*).

As Daniel T. Willingham writes on page 24, humans say they value accuracy. Somehow, though, they let emotions get in the way of seeing the world for how it truly is. This is where science can help us: by shining a light on facts in an uncertain universe, in uncertain times. SA

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The Science Behind the Debates

16

40

4 GRAPPLING WITH THE TRUTH

6 Post-Truth: A Guide for the Perplexed
If politicians can lie without condemnation, what are scientists to do? *By Kathleen Higgins*

8 Why Good Thoughts Block Better Ones
The brain's tendency to stick with familiar ideas can literally blind us to superior solutions. *By Merim Bilalić and Peter McLeod*

14 Why People "Fly from Facts"
The appeal of untestable beliefs and how they lead to a polarized society. *By Troy Campbell and Justin Friesen*

16 5 Things We Know to Be True
A compendium of irrefutable facts for these fact-starved times. *By Michael Shermer, Harriet Hall, Ray Pierrehumbert, Paul Offit and Seth Shostak*

24 Trust Me, I'm a Scientist
Why so many people choose not to believe what scientists say. *By Daniel T. Willingham*

25 CLIMATE

26 7 Answers to Climate Contrarian Nonsense
Evidence for human interference with Earth's climate continues to accumulate, despite the naysayers. *By John Rennie*

34 What to Believe in Antarctica's Great Ice Debate
Most climate scientists argue that, yes, Antarctica is losing mass in a warming world. *By Shannon Hall*

40 How to Break the Climate Deadlock
Will nations ever come together to keep climate out of the severe danger zone? *By Naomi Oreskes*

46 Consilience and Consensus
Or why climate skeptics are wrong. *By Michael Shermer*

47 VACCINES

48 Straight Talk about Vaccination
Parents need better information, ideally before a baby is born. *By Matthew F. Daley and Jason M. Glanz*

50 Fact or Fiction?: Vaccines Are Dangerous
Overwhelming medical evidence proves that negative side effects are rare and minor. *By Dina Fine Maron*

54 Safer by Kindergarten
School immunization laws are working. *By Mark Fischetti and Jan Willem Tulp*

55 GUNS

56 The Gunfighter
A researcher studies the consequences of the ubiquity of guns in the U.S. *By Meredith Wadman*

62 Journey to Gunland
More firearms do not keep people safe, hard numbers show. Why do so many Americans believe the opposite? *By Melinda Wenner Moyer*

72 A Plan to Prevent Gun Suicides
Firearm sellers have become unlikely allies of public health authorities in the effort to block people from killing themselves. *By Nancy Shute*

74 Gun Science
How data can help clarify the gun-control debate. *By Michael Shermer*

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50

62

76

94

75 FOOD

76 Are Engineered Foods Evil?
Proponents of genetically modified crops say the technology is the only way to feed a warming, increasingly populous world. Critics say we tamper with nature at our peril. Who is right?
By David H. Freedman

82 The "True" Human Diet
From the standpoint of paleoecology, the so-called Paleo diet is a myth.
By Peter S. Ungar

84 Building a Better Harvest
Scientists are learning to manipulate the complex conversation that plants have with microbes, pests, nutrients and other elements of the phytobiome in hopes of averting a future famine.
By Marla Broadfoot

92 Paleo Diets, GMOs and Food Taboos
What do we mean by "natural"?
By Michael Shermer

93 EVOLUTION VS. CREATIONISM

94 15 Answers to Creationist Nonsense
Opponents of evolution want to make a place for creationism by tearing down real science, but their arguments don't hold up. *By John Rennie*

104 50 Years Ago: Repeal of Tennessee's "Monkey Law"
The statute that got John Scopes in trouble back in 1925 was finally repealed in 1967—but the teaching of evolution in public schools is still not entirely safe.
By Glenn Branch and Ann Reid

108 Should Science Speak to Faith?
Two prominent defenders of science exchange their views on how scientists ought to approach religion and its followers. *By Lawrence M. Krauss and Richard Dawkins*

DEPARTMENTS

1 FROM THE EDITOR
Science Lights the Way

112 END NOTE
When Facts Backfire *By Michael Shermer*

GETTY IMAGES (*gun and vegetables*)

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grappling with the truth

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In a perfect world, debates about the environment, public health and technology would be objective, reasoned, intellectually honest and grounded in evidence, but there are many forces working against that ideal. The first article in this section explains why in today's "post-truth" world such high expectations no longer hold and lies spread with abandon (*page 6*). People will always dispute the validity of facts, of course, but another story highlights research that shows they often go a step further and reframe an issue in untestable ways (*page 14*). That's a problem because while scientific truths are always provisional at some level, there are plenty of things we know with certainty. Our experts list more than a dozen irrefutable facts (*page 16*). At the end of the day, however, many people say that they trust scientists in general but part company with them on specific issues. Is it any wonder, given the circumstances, that current debates about public policy and personal choices are so fraught? We only hope that by learning more about our biases and tendencies, both innate and acquired, we may one day better grapple with the truth.

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POST-TRUTH: A Guide for the Perplexed

If politicians can lie without condemnation, what are scientists to do?

By Kathleen Higgins

THE OXFORD DICTIONARIES NAMED "POST-TRUTH" AS THEIR 2016 Word of the Year. It must sound alien to scientists. Science's quest for knowledge about reality presupposes the importance of truth, both as an end in itself and as a means of resolving problems. How could truth become passé? For philosophers like me, post-truth also goes against the grain. But in the wake of the 2016 U.S. presidential election and the seemingly endless campaigns preceding it, author Ralph Keyes's 2004 declaration that we have arrived in a post-truth era seems distressingly plausible.

Post-truth refers to blatant lies being routine across society, and it means that politicians can lie without condemnation. This is different from the cliché that all politicians lie and make promises they have no intention of keeping—this still expects honesty to be the default position. In a post-truth world, this expectation no longer holds.

This can explain the current political situation in the U.S. and elsewhere. Public tolerance of inaccurate and undefended allegations, non sequiturs in response to hard questions and outright denials of facts is shockingly high. Repetition of talking points passes for political discussion, and serious interest in issues and options is treated as the idiosyncrasy of wonks. The lack of public indignation when political figures claim disbelief in response to growing scientific evidence of the reality of climate change is part of this larger pattern. "Don't bother me with facts" is no longer a punchline. It has become a political stance. It's worth remembering that it has not always been this way: the exposure of former U.S. president Richard Nixon's lies was greeted with outrage.

One might be tempted to blame philosophy for post-truth. Some of us write about epistemic relativism, the view that truth can vary depending on the context. Yet relativism is itself relative. An extreme relativist might hold that the truth varies from person to person, a position that does not leave much room for debate. But more rational positions can also involve at least a modicum of relativism. In a sense, even 18th-century philosopher Immanuel Kant's quite sensible contention that we can never know what things are like "in themselves"—independent of how our minds format what we perceive—is a relativistic position. It implies that what is true of the world for humans is probably different from what is true for a fly. Entomologists would surely agree.

More radical forms of relativism are often denounced as undermining basic values. Friedrich Nietzsche, the 19th-century philosopher who is often invoked to justify post-truth, was such a relativist, and he does suggest at times that deception is rife and should not be categorically rejected. His point is to complicate our view of human behavior and to object to moral certainties that encourage black-and-white judgments about what's good and what's evil. Thus, he denies that there are moral facts, saying that we have only "moral interpretations," and in doing so he denies that moral assertions are unconditionally true. But this does not mean there is no truth. Even when he claims that our truths amount to our "irrefutable errors," he is pointing to the exaggerated clarity of abstractions by comparison with empirical reality.

In fact—contrary to how he is often presented—Nietzsche held intellectual honesty at a premium. His most strenuous rejections of "truth" are mostly directed not at truth but at what has been asserted as true. Yes, Nietzsche was an elitist who was skeptical of democracy, and so his work does not necessarily fault leaders for talking

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down to the public. But it also points out the inconsistency of religious teachers who assume they have the right to lie.

When political leaders make no effort to ensure that their "facts" will bear scrutiny, we can only conclude that they take an arrogant view of the public. They take their right to lie as given, perhaps particularly when the lies are transparent. Many among the electorate seem not to register the contempt involved, perhaps because they would like to think that their favored candidate is at least well intentioned and would not deliberately mislead them.

Much of the public hears what it wants to hear because many people get their news exclusively from sources whose bias they agree with. But contemptuous leaders and voters who are content with hand-waving and entertaining bluster undermine the democratic idea of rule by the people. The irony is that politicians who benefit from post-truth tendencies rely on truth, too, but not because they adhere to it. They depend on most people's good-natured tendency to trust that others are telling the truth, at least the vast majority of the time.

Scientists and philosophers should be shocked by the idea of post-truth, and they should speak up when scientific findings are ignored by those in power or treated as mere matters of faith. Scientists must keep reminding society of the importance of the social mission of science—to provide the best information possible as the basis for public policy. And they should publicly affirm the intellectual virtues that they so effectively model: critical thinking, sustained inquiry and revision of beliefs on the basis of evidence. Another line from Nietzsche is especially pertinent now: "Three cheers for physics!—and even more for the motive that spurs us toward physics—our honesty!" SA

Kathleen Higgins teaches and writes on Nietzsche, aesthetics and philosophy of emotion at the University of Texas at Austin.

Illustration by Hannah Salyer

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WHY GOOD THOUGHTS BLOCK BETTER ONES

While we are working through a problem, the brain's tendency to stick with familiar ideas can literally blind us to superior solutions

By Merim Bilalić and Peter McLeod

Illustration by Danny Schwartz

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IN A CLASSIC 1942 EXPERIMENT, AMERICAN PSYCHOLOGIST ABRAHAM LUCHINS ASKED volunteers to do some basic math by picturing water jugs in their mind. Given three empty containers, for example, each with a different capacity—21, 127 and three units of water—the participants had to figure out how to transfer liquid between the containers to measure out precisely 100 units. They could fill and empty each jug as many times as they wanted, but they had to fill the vessels to their limits. The solution was to first fill the second jug to its capacity of 127 units, then empty it into the first to remove 21 units, leaving 106, and finally to fill the third jug twice to subtract six units for a remainder of 100. Luchins presented his volunteers with several more problems that could be solved with essentially the same three steps; they made quick work of them. Yet when he gave them a problem with a simpler and faster solution than the previous tasks, they failed to see it.

This time Luchins asked the participants to measure out 20 units of water using containers that could hold 23, 49 and three liquid units. The solution is obvious, right? Simply fill the first jug and empty it into the third one: 23 – 3 = 20. Yet many people in Luchins's experiment persisted to solve the easier problem the old way, emptying the second container into the first and then into the third twice: 49 – 23 – 3 – 3 = 20. And when Luchins gave them a problem that had a two-step solution—but could not be solved using the three-step method to which the volunteers had become accustomed—they gave up, saying it was impossible.

The water jug experiment is one of the most famous examples of the *Einstellung* effect: the human brain's dogged tendency to stick with a familiar solution to a problem—the one that first comes to mind—and to ignore alternatives. Often this type of thinking is a useful heuristic. Once you have hit on a successful method to, say, peel garlic, there is no point in trying an array of different techniques every time you need a new clove. The trouble with this cognitive shortcut, however, is that it sometimes blinds people to more efficient or appropriate solutions than the ones they already know.

Building on Luchins's early work, psychologists replicated the *Einstellung* effect in many different laboratory studies with both novices and experts exercising a range of mental abilities, but exactly how and why it happened was never clear. Recently, by recording the eye movements of highly skilled chess players, we have solved the mystery. It turns out that people under the influence of this cognitive shortcut are literally blind to certain details in their environment that could provide them with a more effective solution. New research also suggests that many different cognitive biases discovered by psychologists over the years—those in the courtroom and the hospital, for instance—are in fact variations of the *Einstellung* effect.

BACK TO SQUARE ONE

SINCE AT LEAST THE EARLY 1990S, psychologists have studied the *Einstellung* effect by recruiting chess players of varying skill levels, from amateur to grand master. In such experiments, researchers have presented players with specific arrangements of chess pieces on virtual chessboards and asked them to achieve a checkmate in as few moves as possible. Our own studies, for instance, provided expert chess players with scenarios in which they could accomplish a checkmate using a well-known sequence called smothered mate. In this five-step maneuver, the queen is sacrificed to draw one of the opponent's pieces onto a square to block off the king's escape route. The players also had the option to checkmate the king in just three moves with a much less familiar sequence. As in Luchins's water jug studies, most of the players failed to find the more efficient solution.

During some of these studies, we asked the players what was going through their mind. They said they had found the smothered mate solution and insisted they were searching for a shorter one, to no avail. But the verbal reports offered no insight into why they could not find the swifter solution. In 2007 we decided

IN BRIEF

The *Einstellung* effect is the brain's tendency to stick with the most familiar solution to a problem and stubbornly ignore alternatives.

Psychologists have known about this mental phenomenon since the 1940s, but only now do they have a solid understanding of how it happens.

In recent eye-tracking experiments, familiar ideas blinded chess players to areas of a chessboard that would have provided clues to better solutions.

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to try something a little more objective: tracking eye movements with an infrared camera. Which part of the board people looked at and how long they looked at different areas would unequivocally tell us which aspects of the problem they were noticing and ignoring.

In this experiment, we followed the gaze of five expert chess players as they examined a board that could be solved either with the longer smothered mate maneuver or with the shorter three-move sequence. After an average of 37 seconds, all the players insisted that the smothered mate was the speediest possible way to corner the king. When we presented them with a board that could be solved only with the three-sequence move, however, they found it with no problem. And when we told the players that this same swift checkmate had been possible in the previous chessboard, they were shocked. "No, it is impossible," one player exclaimed. "It is a different problem; it must be. I would have noticed such a simple solution." Clearly, the mere possibility of the smothered mate move was stubbornly masking alternative solutions. In fact, the *Einstellung* effect was powerful enough to temporarily lower expert chess masters to the level of much weaker players.

ANY DATA THAT DO NOT FIT THE SOLUTION OR THEORY WE HAVE ALREADY CLUNG TO ARE IGNORED OR DISCARDED.

The infrared camera revealed that even when the players said they were looking for a faster solution—and indeed believed they were doing so—they did not actually shift their gaze away from the squares they had already identified as part of the smothered mate move. In contrast, when presented with the one-solution chessboard, players initially looked at the squares and pieces important for the smothered mate and, once they realized it would not work, directed their attention toward other squares and soon hit on the shorter solution.

BASIS FOR BIAS

IN 2013 Heather Sheridan, now at the University of Albany, S.U.N.Y., and Eyal M. Reingold of the University of Toronto published studies that corroborate and complement our eye-tracking experiments. They presented 17 novice and 17 expert chess players with two different situations. In one scenario, a familiar checkmate maneuver such as the smothered mate was advantageous but second best to a distinct and less obvious solution. In the second situation, the more familiar sequence would be a clear blunder. As in our experiments, once amateurs and master chess players locked onto the helpful familiar maneuver, their eyes rarely drifted to squares that would clue them in to the better solution. When the well-known sequence was obviously a mistake, however, all the experts (and most of the novices) detected the alternative.

The *Einstellung* effect is by no means limited to controlled experiments in the lab or even to mentally challenging games like chess. Rather it is the basis for many cognitive biases. English philosopher, scientist and essayist Francis Bacon was especially eloquent about one of the most common forms of cognitive bias in his 1620 book *Novum Organum:* "The human understanding when it has once adopted an opinion … draws all things else to support and agree with it. And though there be a greater number and weight of instances to be found on the other side, yet these it either neglects or despises, or else by some distinction sets aside and rejects.… Men … mark the events where they are fulfilled, but where they fail, though this happen much oftener, neglect and pass them by. But with far more subtlety does this mischief insinuate itself into philosophy and the sciences, in which the first conclusion colours and brings into conformity with itself all that comes after."

In the 1960s English psychologist Peter Wason gave this particular bias a name: "confirmation bias." In controlled experiments, he demonstrated that even when people attempt to test theories in an objective way, they tend to seek evidence that confirms their ideas and to ignore anything that contradicts them.

In *The Mismeasure of Man,* for example, Stephen Jay Gould of Harvard University reanalyzed data cited by researchers trying to estimate the relative intelligence of different racial groups, social classes and sexes by measuring the volumes of their skulls or weighing their brains, on the assumption that intelligence was correlated with brain size. Gould uncovered massive data distortion. On discovering that French brains were on average smaller than their German counterparts, French neurologist Paul Broca explained away the discrepancy as a result of the difference in average body size between citizens of the two nations. After all, he could not accept that the French were less intelligent than the Germans. Yet when he found that women's brains were smaller than those in men's noggins, he did not apply the same correction for body size, because he did not have any problem with the idea that women were less intelligent than men.

Somewhat surprisingly, Gould concluded that Broca and others like him were not as reprehensible as we might think. "In most cases discussed in this book we can be fairly certain that biases … were unknowingly influential and that scientists believed they were pursuing unsullied truth," Gould wrote. In other words, just as we observed in our chess experiments, comfortably familiar ideas blinded Broca and his contemporaries to the errors in their reasoning. Here is the real danger of the *Einstellung* effect. We may believe that we are thinking in an open-minded way, completely unaware that our brain is selectively directing attention away from aspects of our environment that could inspire new thoughts. Any data that do not fit the solution or theory we have already clung to are ignored or discarded.

The surreptitious nature of confirmation bias has unfortunate consequences in everyday life, as documented in studies on decision making among doctors and juries. In a review of errors in medical thought, physician Jerome Groopman noted that in most cases of misdiagnosis, "the doctors didn't stumble because of their ignorance of clinical facts; rather, they missed diagnoses because they fell into cognitive traps." When doctors inherit a patient from another doctor, for example, the first clinician's diagnosis can blind the second to important and contradictory details of the patient's health that might change the diagnosis. It is easier to just accept the diagnosis—the "solution"—that is already in front of them than to rethink the entire situation. Similarly, radiologists examining chest x-rays often fixate on the first abnormality they find and fail to notice further signs of illness that should be obvious, such as a swelling

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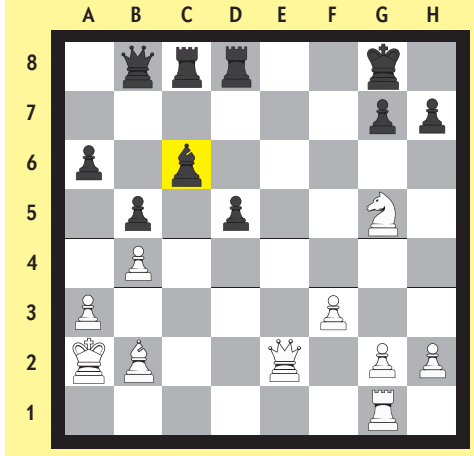
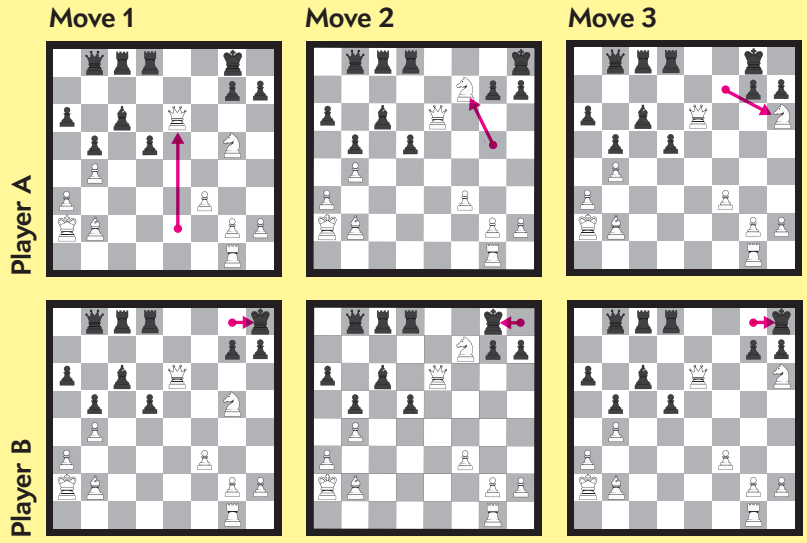
THE SCIENCE BEHIND THE DEBATES

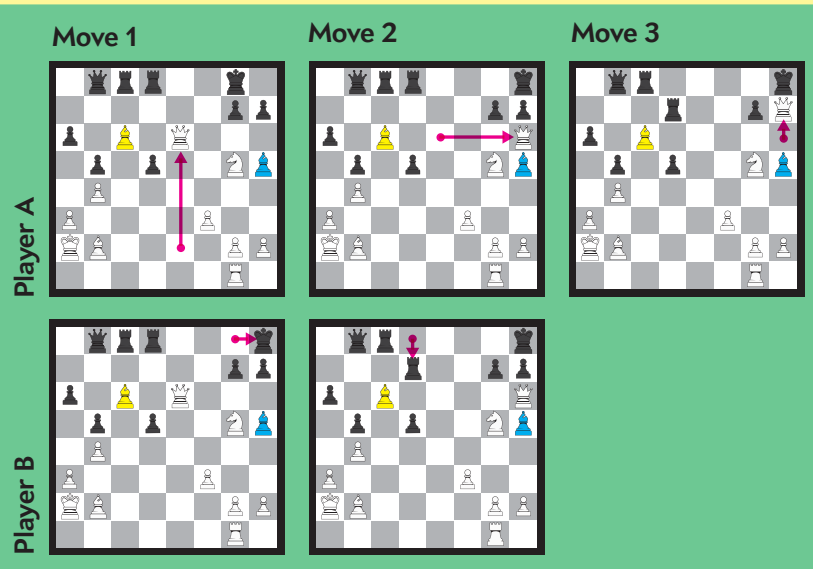
Much More Than Meets the Eye

The intellectually demanding game of chess has proved a wonderful way for psychologists to study the *Einstellung* effect—the brain's tendency to stick with solutions it already knows rather than looking for potentially superior ones. Experiments have shown that this cognitive bias literally changes how even expert chess players see the board in front of them.

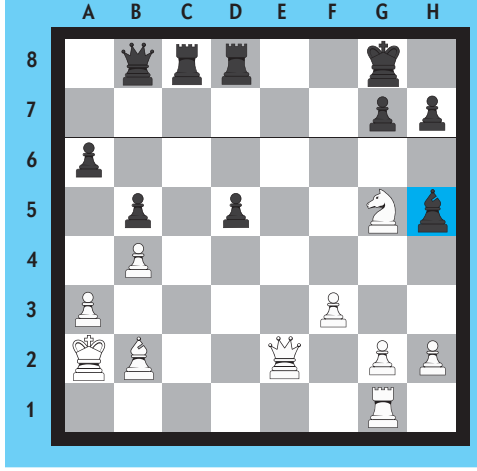
Two-Solution Problem







One-Solution Problem



Chess Masters Fail to See the Quickest Path to Victory

In a well-known five-sequence move called smothered mate (*yellow*), player A begins by moving his queen from E2 to E6, backing player B's king into a corner. Player A then repeatedly threatens to take B's king with a knight, forcing player B to dodge. As an act of deliberate sacrifice, player A moves his queen adjacent to B's king, allowing player B to take the queen with a rook. To end the game, player A moves his knight to F7, boxing in B's king with no chance of escape. In recent experiments, psychologists presented master chess players with the two-solution board shown, which could be won using either the smothered mate or a much swifter three-step solution (*green*). The players were told to achieve checkmate as quickly as possible, but once they recognized the smothered mate as a possibility, they became seemingly incapable of noticing the more efficient strategy. When presented with a nearly identical board on which the position of one bishop had shifted (*blue*), eliminating the smothered mate as an option, the players did recognize the speedier solution, however.

Illustration by George Retseck

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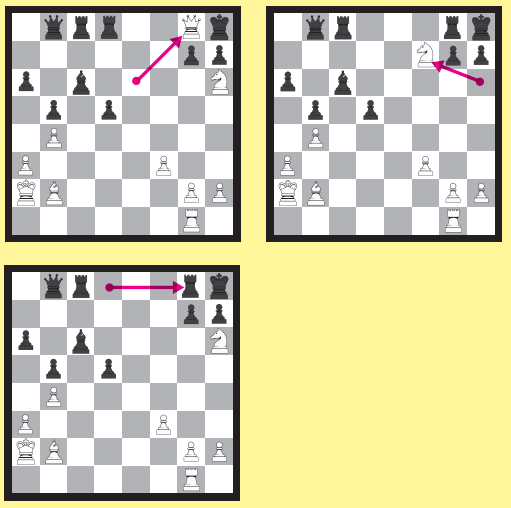
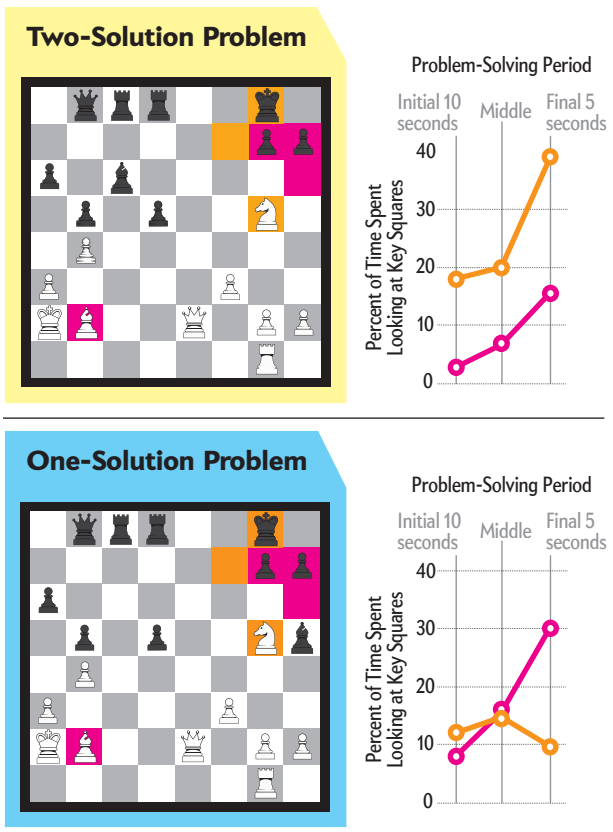


The Explanation: Tunnel Vision

Eye-tracking devices revealed that as soon as chess players hit on the smothered mate as a solution, they spent far more time looking at squares relevant to that familiar maneuver (*orange*) than at squares pertinent to the more efficient three-step sequence (*magenta*), despite insisting that they were searching for alternatives. Conversely, when the smothered mate was not viable, the players' gaze shifted to regions of the chessboard crucial to the swifter strategy.



that could indicate cancer. If those secondary details are presented alone, however, radiologists see them right away.

Related studies have revealed that jurors begin to decide whether someone is innocent or guilty long before all the evidence has been presented. In turn, their initial impressions of the defendant change how they weigh subsequent evidence and even their memory of evidence they saw before. Likewise, if an interviewer finds a candidate to be physically attractive, he or she will automatically perceive that person's intelligence and personality in a more positive light, and vice versa. These biases, too, are driven by the *Einstellung* effect. It is easier to make a decision about someone if one maintains a consistent view of that person rather than sorting through contradictory evidence.

Can we learn to resist the *Einstellung* effect? Perhaps. In our chess experiments and the follow-up experiments by Sheridan and Reingold, some exceptionally skilled experts, such as grand masters, did in fact spot the less obvious optimal solution even when a slower but more familiar sequence of moves was possible. This suggests that the more expertise someone has in their field—whether chess, science or medicine—the more immune they are to cognitive bias.

But no one is completely impervious; even the grand masters failed when we made the situation tricky enough. Actively remembering that you are susceptible to the *Einstellung* effect is another way to counteract it. When considering the evidence on, say, the relative contribution of man-made and naturally occurring greenhouse gases to global temperature, remember that if you already think you know the answer, you will not judge the evidence objectively. Instead you will notice evidence that supports the opinion you already hold, evaluate it as stronger than it really is and find it more memorable than evidence that does not support your view.

We must try and learn to accept our errors if we sincerely want to improve our ideas. English naturalist Charles Darwin came up with a remarkably simple and effective technique to do just this. "I had … during many years, followed a golden rule, namely, that whenever a published fact, a new observation or thought came across me, which was opposed by my general results, to make a memorandum of it without fail and at once," he wrote. "For I had found by experience that such facts and thoughts were far more apt to escape from memory than favourable ones." SA

Merim Bilalić is a professor of cognitive psychology at the University of Northumbria at Newcastle. His research on the *Einstellung* effect won the British Psychological Society's Award for Outstanding Doctoral Research Contributions to Psychology in 2008. His latest book is *The Neuroscience of Expertise* (Cambridge University Press, 2017).

Peter McLeod is an emeritus fellow at Queen's College at the University of Oxford. He is chair of the Oxford Foundation for Theoretical Neuroscience and Artificial Intelligence.

MORE TO EXPLORE

The Einstellung Effect in Anagram Problem Solving: Evidence from Eye Movements. J. J. Ellis and E. M. Reingold in *Frontiers in Psychology,* Vol. 5, Article 679; July 2014.

Baboons (*Papio papio*), but Not Humans, Break Cognitive Set in a Visuomotor Task. S. M. Pope et al. in *Animal Cognition,* Vol. 18, No. 6, pages 1339–1346; November 2015.

Magicians Fix Your Mind: How Unlikely Solutions Block Obvious Ones. C. Thomas and A. Didierjean in *Cognition,* Vol. 154, pages 169–173; September 2016.

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Why People "Fly from Facts"

Research shows the appeal of untestable beliefs and how they lead to a polarized society

By Troy Campbell and Justin Friesen

THERE WAS A SCIENTIFIC STUDY THAT SHOWED vaccines cause autism." "Actually, the researcher in that study lost his medical license, and overwhelming research since then has shown no link between vaccines and autism." "Well, regardless, it's still my personal right as a parent to make decisions for my child." Does that exchange sound familiar? A debate that starts with testable factual statements, but then, when the truth becomes inconvenient, the person takes a flight from facts.

As public debate rages about issues such as immunization, Obamacare and same-sex marriage, many people try to use science to bolster their arguments. And because it's becoming easier to test and establish facts—whether in physics, psychology or policy—many have wondered why bias and polarization have not been defeated. When people are confronted with facts, such as the well-established safety of immunization, why do these facts seem to have so little effect?

Our recent research, published in 2015 in the *Journal of Personality and Social Psychology,* examined a slippery way by which people get away from facts that contradict their beliefs. Of course, sometimes people just dispute the validity of specific facts. But we find that sometimes they go one step further and, as in the opening example, reframe an issue in untestable ways. This makes potential important facts and science ultimately irrelevant to the issue.

Let's consider the issue of same-sex marriage. Facts could be relevant to whether it should be legal—for example, if data showed that children raised by same-sex parents are worse off—or just as well-off—as children raised by opposite-sex parents. But what if those facts contradict one's views?

We presented 174 American participants who supported or opposed same-sex marriage with (supposed) scientific facts that supported or disputed their position. When the facts opposed their views, our participants—on both sides of the issue—were more likely to state that same-sex marriage isn't actually about facts, it's more a question of moral opinion. But when the facts were on their side, they more often stated that their opinions were fact-based and much less about morals. In other words, we observed something beyond the denial of particular facts: we observed a denial of the relevance of facts.

In a similar study using 117 religious participants, we had some read an article critical of religion. Believers who were especially high (but not low) in religiosity were more likely to turn to more untestable "blind faith" arguments as reasons for their beliefs than to arguments based in factual evidence, compared with those who read a neutral article.

These experiments show that when people's beliefs are threatened, they often take flight to a land where facts do not matter. In scientific terms, their beliefs become less "falsifiable" because they can no longer be tested scientifically for verification or refutation.

For instance, sometimes people dispute government policies based on the argument that they don't work. Yet if facts suggest that the policies do work, the same person might stay resolvedly against the argument based on principle. We can see this on both sides of the political spectrum, whether it's conservatives and Obamacare or liberals and the "surge" in Iraq in 2007.

One would hope that objective facts could allow people to reach consensus more easily, but American politics are more polarized than ever. Could this polarization be a consequence of feeling free of facts?

While it is difficult to objectively test that idea, we can experimentally assess a fundamental question: When people are made to see their important beliefs as relatively less rather than more testable, does it increase polarization and commitment to desired beliefs? Two experiments we conducted suggest so.

In an experiment with 179 Americans (conducted during President Barack Obama's tenure), we reminded roughly half of participants that much of Obama's policy performance was empirically testable and did not remind the other half. Then participants rated Obama's performance on five domains (such as job creation). Comparing opponents and supporters of Obama, we found that the reminder of testability reduced the average polarized assessments of Obama's performance by about 40 percent.

To further test the hypothesis that people strengthen their desired beliefs when the beliefs are free of facts, we looked at a sample of 103 participants that varied from highly to moderately re-

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ligious. We found that when highly (but not more moderately) religious participants were told that God's existence will always be untestable, they reported stronger desirable religious beliefs afterward (such as the belief that God was looking out for them), relative to when they were told that one day science might be able to investigate God's existence.

Together these findings show, at least in some cases, when testable facts are less a part of the discussion, people dig deeper into the beliefs they wish to have—such as viewing a politician in a certain way or believing God is constantly there to provide support. These results bear similarities to the many studies that find when facts are fuzzier, people tend to exaggerate desired beliefs.

So after examining the power of untestable beliefs, what have we learned about dealing with human psychology? We have learned that bias is a disease and to fight it we need a healthy treatment of facts and education. We find that when facts are injected into the conversation, the symptoms of bias become less severe. But, unfortunately, we have also learned that facts can only do so much. To avoid coming to undesirable conclusions, people can fly from the facts and use other tools in their deep, belief-protecting toolbox.

With the disease of bias, then, societal immunity is better achieved when we encourage people to accept ambiguity, engage in critical thinking and reject strict ideology. This society is something the Common Core State Standards for education and at times *The Daily Show* are at least in theory attempting to help create. We will never eradicate bias—not from others, not from ourselves and not from society. But we can become a people more free of ideology and less free of facts. SA

Troy Campbell is assistant professor of marketing at the University of Oregon. He studies how our beliefs and identities centrally affect everyday experiences and thought. **Justin Friesen** is assistant professor of psychology at the University of Winnipeg. He studies the psychological and motivational factors that perpetuate social and economic inequality.

Illustration by Thomas Fuchs

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5 THINGS WE KNOW TO BE TRUE

A COMPENDIUM OF IRREFUTABLE FACTS FOR THESE FACT-STARVED TIMES

SCIENTIFIC TRUTHS are always provisional at some level. We once believed that the continents were fixed on the surface of Earth; now we know they move. We thought the universe was static; now we know it is expanding. We thought margarine was healthier than butter and that hormone-replacement therapy was the right treatment for vast numbers of postmenopausal women; now we know better.

But while scientists do not know everything, there is plenty they

Illustrations by Red Nose Studio

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IN BRIEF

A small but vocal contingent of truth deniers refuse to accept scientific consensus on certain issues.

We thought this would be a good time to clearly and emphatically lay out the case for several well-established—but, in some circles, strangely contentious—scientific truths.

Consider this a cheat sheet for debates with the antiscience crowd.

do know. Especially within this political climate, it is dispiriting to see how many people—including pundits—bizarrely reject some of the most basic, evidence-based truths that underlie modern science.

We ordinarily report on the latest advances in scientific and technological research, but we thought it appropriate to take a step back and discuss some of science's firmly established facts. There is essentially no debate among legitimate scientists about these truths, which are based on verifiable evidence, which have been accepted for decades and which have only become more strongly established as new evidence continues to accumulate.

Psychological research has shown that being confronted with that mounting evidence can actually harden the positions of the truth deniers, so we do not pretend that the essays that follow will fix the problem. Nevertheless, we feel it is our duty to point out that some things actually are true, even in the constantly growing and evolving world of science.

—The Editors

MONSTERS, INC.—Bigfoot, the Loch Ness monster and similar creatures do not exist. The idea that large, unknown animals roam the woods of the Pacific Northwest, glide through chilly Scottish waters and hike the Himalayas is eerily appealing, but the evidence is basically zero.

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Evolution Is the Only Reasonable Explanation for the Diversity of Life on Earth

BY MICHAEL SHERMER

ON JANUARY 14, 1844, CHARLES Darwin wrote a letter to his friend Joseph Hooker, recalling his voyage around the world on the HMS *Beagle*. After five years at sea and seven years at home thinking about the origin of species, Darwin came to this conclusion: "At last gleams of light have come, & I am almost convinced (quite contrary to opinion I started with) that species are not (it is like confessing a murder) immutable."

Like confessing a murder. Dramatic words. But it doesn't take a rocket scientist—or an English naturalist—to understand why a theory on the origin of species by means of natural selection would be so controversial. If new species are created naturally—not supernaturally—what place, then, for God? No wonder that more than a century and a half later people of some religious faiths still find the theory so terribly threatening. But in those intervening years scientists have found so much evidence in support of the theory that it would be truly astonishing if it turned out not to be true—as shocking as if the germ theory of disease fell apart or if astrophysicists were forced to abandon the big bang model of the universe. Why? Because of a convergence of evidence from many lines of inquiry.

For example: Comparing data from research in population genetics, geography, ecology, archaeology, physical anthropology and linguistics, scientists discovered that Australian Aborigines are genetically more closely related to South Asians than they are to African blacks—which makes sense from an evolutionary perspective because the migration pattern of humans out of Africa led them to Asia and then to Australia.

The consistency of dating techniques also gives us confidence that the theory is true. Uranium-lead, rubidium-strontium and potassium-argon dating, for example, are all reasonably consistent in their determination of the age of rocks and fossils. The ages are given in estimates, but the margins of error are in the range of 1 percent. It is not as if one scientist finds that a fossil hominin is 1.2 million years old while another one finds it is 10,000 years old.

Not only are the dates consistent, but the fossils also show intermediate stages—something antievolutionists still insist don't exist. There are now at least six intermediate fossil stages in the evolution of whales, for instance, and more than a dozen fossil hominins, several of which must have been intermediate with humans since the hominins branched off from chimpanzees six million years ago. And geologic strata consistently reveal the same sequence of fossils. Trilobites and mammals are separated by many millions of years, so finding a fossil horse in the same geologic stratum as a trilobite—or even more drastically, a fossil hominin in the same stratum as a dinosaur—would prove problematic for the theory of evolution, but that has never happened.

Finally, vestigial structures are signs of evolutionary history. The Cretaceous snake *Pachyrhachis problematicus* had small hind limbs, which are gone in most of today's snakes. Modern whales retain a tiny pelvis for hind legs that existed in their land-mammal ancestors. Likewise, flightless birds have wings. And of course, humans are replete with useless vestigial structures—a distinctive sign of our evolutionary ancestry—such as wisdom teeth, male nipples, body hair, the appendix and the coccyx.

As the great geneticist and evolutionary theorist Theodosius Dobzhansky famously noted, "Nothing in biology makes sense except in the light of evolution."

Michael Shermer is publisher of *Skeptic* magazine, a columnist for *Scientific American* and a presidential fellow at Chapman University. His latest book is *Heavens on Earth*. Follow him on Twitter @michaelshermer

GMOs ARE NOT SCARY—"Frankenfoods" sound like a terrifying concept, but despite extensive testing, genetically modified organisms have never been shown to be dangerous to human health.

100% BS—No, we do not use only 10 percent of our brainpower. Nobody knows where this "fact" even came from, but it's nonsense.

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Homeopathy Has No Basis in Science

BY HARRIET HALL

HOMEOPATHY IS A SYSTEM OF medicine that purports to treat disease with minute doses of substances that in a healthy person would produce symptoms of that disease. It is based on the unscientific thinking of a single misguided individual, a German doctor named Samuel Hahnemann, who invented it in the early 1800s.

Homeopathy not only doesn't work; it couldn't possibly work. It is inconsistent with our basic knowledge of physics, chemistry and biology. Oliver Wendell Holmes thoroughly debunked it in 1842 with his essay "Homeopathy and Its Kindred Delusions." He would have been appalled to think anyone could still believe it in 2016.

Few users of homeopathy have bothered to inform themselves about what they are taking or the wacky ideas behind it. The simplest way to explain homeopathic theory is with this example: If coffee keeps you awake, dilute coffee will put you to sleep—the more dilute, the stronger the effect. If you dilute it until there isn't a single molecule of coffee left, it will be even stronger. (The water will somehow remember the coffee that is no longer there.) If you drip the coffee-free water onto a sugar pill and let it evaporate, the memory of coffee will be transferred to the sugar pill, and the pill will relieve insomnia.

If any of that makes sense to you, you should be worried.

You wouldn't think anyone would buy a medicine that contained no active ingredient, but they do. A product called Oscillococcinum is sold in most American pharmacies, bringing in an estimated $15 million a year from customers hoping to relieve the symptoms of flu and colds. The name is that of the oscillating bacteria that a French physician, Joseph Roy, imagined he could see in the blood of flu victims and in duck liver; no one else ever saw them. The box says the active ingredient is *Anas barbariae* 200 CK HPUS. That means Muscovy duck (the heart and liver), and it means they diluted it 1:100 and repeated that process 200 times, "succussing" it after each dilution (it is shaken, not stirred). Any chemistry student can use Avogadro's number to calculate that by the 13th dilution, there is only a 50–50 chance that a single molecule of duck remains, and by the 200th dilution the duck is history. All that remains is the quack.

Homeopaths' prescribing methods are unbelievably silly. They ask a laundry list of irrelevant questions (What color are your eyes? What foods do you dislike? What are you afraid of?). They consult two books. The first is a *Repertory* listing remedies for every possible symptom—for example, clairvoyance (yes, it considers this a symptom), dental caries and "tearful" (sic). The second is a *Materia Medica* listing the symptoms associated with each remedy ("dreams of robbers" are linked to table

Harriet Hall is a retired family physician who writes about medicine, alternative medicine, science, quackery and critical thinking. She is one of the founders and editors of the Science-Based Medicine blog, a fellow of the Committee for Skeptical Inquiry and a board member of the Society for Science-Based Medicine.

THIS IDEA IS ALL WET—You do not need to drink eight glasses of water a day. You do have to replace fluids lost to urine and perspiration, but some comes from food, and there's no set amount.

EXPENSIVE URINE—Unless you have a deficiency or no access to healthy food or a balanced diet, vitamin supplements are pretty much a waste of time and money.

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salt!). Yes, dilute table salt and pretty much anything imaginable can be a remedy. Some of my favorites: Berlin wall, eclipsed moonlight, dog's earwax and the south pole of a magnet. It's absurd, but an estimated five million adults and one million children use homeopathic remedies every year in the U.S., mostly self-prescribed and purchased in a pharmacy.

Even though there are published studies claiming that homeopathy works, you can find a study to support almost anything, and rigorous scientific reviews of the entire body of research have consistently concluded that it works no better than placebos. As Edzard Ernst, emeritus professor of complementary medicine at the University of Exeter in England, and author Simon Singh have written, "The evidence points towards a bogus industry that offers patients nothing more than a fantasy."

The FDA allows the sale of homeopathic remedies under a "grandfather" clause exempting them from the requirement to demonstrate effectiveness, but it is considering changes in regulation. I wish they would require a label stating, "Contains no active ingredient. For entertainment purposes only." So far people have used homeopathy instead of effective drugs, vaccines and malaria prophylaxis with disastrous results. People have died.

Homeopathy was bunk in 1842, and it remains bunk today. By now we ought to know better.

Climate Change Conspiracy Theories Are Ludicrous

BY RAY PIERREHUMBERT

I'M ALWAYS BAFFLED THAT SOME people have convinced themselves that the scientific consensus underpinning anthropogenic global warming is a vast conspiracy to destroy the American way of life, foist socialism on the unsuspecting masses, or … insert your favorite gripe here.

If it is a conspiracy, it is a truly remarkable one, spanning nearly two centuries and the scientific communities of dozens of nations. The foundations of our understanding of planetary temperature begin with the work in the 1820s of French physicist Joseph Fourier, who established that a planet's temperature is determined by the balance between energy received from the sun and infrared radiation emitted back into space. Quantification of Fourier's basic idea depended on the development of blackbody radiation theory by Austrian Ludwig Boltzmann in the mid-1800s and his German contemporary Gustav Kirchhoff. Irish-born physicist John Tyndall brought carbon dioxide into the picture in the late 19th century by showing that it traps infrared radiation, and Swedish chemist Svante Arrhenius put it all together shortly thereafter.

There were many later developments in the 20th century, culminating in a quite complete theory incorporating both carbon dioxide and water vapor feedback, which Syukuro Manabe developed while working at NOAA's Geophysical Fluid Dynamics Laboratory in the 1960s and 1970s. We have learned plenty since then, but Manabe basically nailed it. Our understanding of the connection between greenhouse gases and global warming rests on the same principles that underlie heat-seeking missiles, weather satellites and infrared remote controls. It would take quite a conspiracy to fake all that.

It would take an even greater conspiracy to fake the changes in Earth's climate that theory predicts and scientists have observed, including higher global average temperatures, rising sea levels, dwindling ice in the Arctic and Antarctic, melting glaciers, increases in the intensity and duration of heat waves, and more. The cabal would also have to fake all the data from past climates that tell us there is no magic mechanism (clouds or otherwise) that will save us from the well-established warming effects of carbon dioxide acting in concert with water vapor. It would have to fake the observations that tell us that subsurface ocean waters are warming—evidence that the energy that is heating the planet's surface is not coming from the oceans. (Energy is conserved, so if the oceans were causing surface warming, then they would be cooling down in response. Conservation is not just a personal virtue—it's the law!) Likewise the carbon isotope and carbon budget data that prove that the carbon dioxide accumulating in the atmosphere really does come from deforestation and burning fossil fuels. It would have to fake the observed conjunction of stratospheric cooling with tropospheric warming, which is characteristic of the influence of carbon dioxide and other long-lived greenhouse gases on the atmosphere.

And so on and so forth. It adds up to an awful lot of stuff to fake and makes faking the moon landing look like a piece of cake.

Science rewards those who overturn previous dogma (think quantum theory versus classical mechanics), so the fact that the basic theory of anthropogenic global warming has weathered all challenges since appearing in its modern form in the 1960s is saying a lot. Global warming is a problem, and we caused it. That's still true even if Donald Trump disagrees. Arguing about the basic existence of the problem has no place in a sane discourse.

Ray Pierrehumbert is Halley Professor of Physics at the University of Oxford.

DON'T FALL OFF THE EDGE—No, just kidding. Earth is not flat. Christopher Columbus knew it when he set sail. You know it, too. Or most of you do, anyway.

NO FREE LUNCH—Free energy and perpetual motion sound great. But thermodynamics says no way, and that's the law.

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THE SCIENCE BEHIND THE DEBATES

Vaccines Do Not Cause Autism

BY PAUL OFFIT

IT HAS BEEN ALMOST 20 YEARS since a paper published in the *Lancet* gave birth to the notion that vaccines caused autism. Since then, more than two dozen studies have refuted the claim, and the original paper has been retracted.

For the most part, the money and time devoted to studying the vaccine-autism hypothesis have been worth it. First, media outlets no longer carry this story under the false mantra of balance, telling two sides when only one is supported by the science. Now the story is one of a disproved claim proposed by a discredited doctor. Second, most parents no longer believe that vaccines cause autism. A recent study showed that 85 percent of parents of children with autism do not believe that vaccines were the cause.

Unfortunately, despite the mountain of evidence refuting the association, a small group of parents still believe that vaccines might cause autism. Their failure to vaccinate their children not only endangers the children but also weakens the "herd immunity" that keeps disease outbreaks contained. There are several plausible reasons why they feel this way.

One possibility is that the cause or causes of autism remain unknown—the same situation that applied to diabetes in the 1800s, when no one knew what caused it or how to treat it. At the time, people proposed a variety of crazy causes and heroic cures. Then, in 1921, Frederick Banting and Charles Best discovered insulin, and all these false beliefs melted away. Until a clear cause and cure for autism emerge, the vaccine hypothesis will be hard to put completely to rest.

Another possibility is that the notion that vaccines cause autism is comforting—certainly far more comforting than studies that have shown a genetic basis. If autism is caused by events occurring outside the womb, then parents can exercise some form of control. If the disorder is genetic, there is no control.

And everyone loves a bogeyman. It is nice to be able to point a finger at an evil force causing autism, especially if it is big pharma or big government. Conspiracy theorists argue that the only reason studies have shown that vaccines do not cause autism is that a vast international conspiracy is hiding the truth. Although only a small group of parents hold this belief, their voices are disproportionally represented on the Internet.

Finally, parents of children with autism often perceive them as developing normally up to about 12 months of age. Then, after receiving a series of vaccines, the child misses speech, language, behavior and communication milestones typically seen in the second year of life. In fact, several studies examining videotapes taken in the first year of life show that these children were not developing normally. But from the parents' perspective, they were.

The most encouraging aspect of the vaccine-autism controversy has been the emergence of academics, clinicians, public health officials and parents who have taken to the Internet, the airways and the print media to represent the science that has exonerated vaccines. As a consequence, the tide has turned. We now hear the voices of parents who are angry that other parents, by choosing not to vaccinate, have put all children at risk.

This societal outcry in favor of vaccines was made all the more immediate by the 2015 measles outbreak, which began at the Disney theme park in California and spread to 189 people, mostly children, in 24 states and the District of Columbia. Sadly, nothing educates better than the virus. Invariably, it is the children who suffer our ignorance.

Paul Offit is a professor of pediatrics in the Division of Infectious Diseases and director of the Vaccine Education Center at Children's Hospital of Philadelphia.

CRIME SEEN—Or rather, not seen. Criminal activity does not increase during the full moon. It can seem that way, even to police officers, because you notice things that confirm your expectations. But despite a handful of suspicious-looking studies, most research says the idea is lunacy.

RATATOUILLE—Treat- so in humans. Animal tests hear that a cure based on

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ing cancer in rodents is not the same as doing have led to many new treatments. But if you rodents is on the way, you should smell a rat.

SA

No Credible Evidence of Alien Visitations Exists

BY SETH SHOSTAK

MILLIONS OF PEOPLE IN THE U.S. claim they have been abducted by aliens, according to a 2013 story in the *Washington Post*. That's an impressive tally for the aliens. And yet the government's response has been tepid. That should tell you something: either the Feds think it's not happening, or they're part of the problem.

Many people believe the latter. They say that the government knows the aliens are here but keeps the evidence under wraps at Area 51 or some other top-secret venue.

But hold on.

Unless extraterrestrials prefer Americans (and exceptionalism aside, why should they?), then the rate of abduction worldwide shouldn't be terribly different from what it is here. Assuming an aliens-without-borders effort, tens of millions of folks around the world have been grabbed by the grays. I think the United Nations would notice. I think you'd notice.

Abductions, of course, are only one component of the so-called UFO phenomenon. The majority of the evidence is composed of sightings—eyewitness accounts, photographs and videos. Most of these can be explained as aircraft, rockets, balloons, bright planets or, occasionally, hoaxes. Some remain unexplained—but that only means they are *unexplained,* not that they are flying saucers, no matter how convinced the people who report them might be. There remains no scientifically validated evidence that extraterrestrials have been here, either recently or in the distant past. The pyramids, the Nazca lines in Peru and all the other artifacts that have been ascribed to ancient astronauts can be straightforwardly explained by human activity.

In fact, few scientists or science museum curators feel that the claim we are being visited is even plausible. Even aside from the formidable technical challenges of interstellar travel, ask yourself this: Why are they here now? *Homo sapiens* has been broadcasting its presence to the universe only since the advent of television and radar. Unless the extraterrestrials come from a very close star system, there has not been adequate time for them to learn of our existence and fly to Earth.

Even if they could get here at the speed of light (which they could not), they would have to live within 35 or so light-years of us—and there are not all *that* many close stars. Besides, high-speed space travel requires an enormous amount of energy. Would you pay a gargantuan utility bill just for a little "catch and release" sportfishing for hominins?

Nevertheless, for decades polls have shown that roughly one third of the populace believes our world is host to cosmic visitors. If despite the lack of good evidence, you insist on believing this is true, you also have to admit they are the best guests you could ever have. They don't kill us, they don't foment unrest, they don't steal the silverware. The Roswell incident was nearly 70 years ago. If aliens have been here since, they deserve good conduct medals.

Seth Shostak is senior astronomer at the SETI Institute, a nonprofit organization that studies the nature of life beyond Earth. He also co-hosts a weekly radio program, *Big Picture Science*.

MORE TO EXPLORE

Why Evolution Is True. Jerry A. Coyne. Viking Adult, 2009.
Global Weirdness. Climate Central. Pantheon, 2012.
The Panic Virus: The True Story behind the Vaccine-Autism Controversy. Seth Mnookin. Simon & Schuster, 2012.
How UFOs Conquered the World: The History of a Modern Myth. David Clarke. Aurum Press, 2015.

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Trust Me, I'm a Scientist

Why so many people choose not to believe what scientists say

By Daniel T. Willingham

A FRIEND OF MINE has long held that a vaccination his son received as an infant triggered his child's autism. He clings to this belief despite a string of scientific studies that show no link between autism and vaccines. When the original paper on such a link was discredited as a fraud, my friend's reaction was that it would become more difficult to persuade people of the dangers of vaccination. He is not alone: nearly half of all Americans believe in the vaccine-autism link or are unsure about it.

The paradox goes deeper. My friend insists that he trusts scientists—and again, in this respect, he is like most Americans. In a 2016 survey by the National Science Foundation, more respondents expressed "a great deal" of confidence in science leaders than in leaders of any other institution except the military. On public policy issues, Americans believe that science leaders are more knowledgeable and impartial than leaders in other sectors of society, such as business or government. Why do people say that they trust scientists in general but part company with them on specific issues?

Many individuals blame the poor quality of science education in the U.S. If kids got more science in school, the thinking goes, they would learn to appreciate scientific opinion on vaccines, climate, evolution and other policy issues. But this is a misconception. Those who know more science have only a slightly greater propensity to trust scientists. The science behind many policy issues is highly specialized, and evaluating it requires deep knowledge—deeper than students are going to get in elementary and high school science classes. A more direct approach would be to educate people about why they are prone to accept inaccurate beliefs in the first place.

Humans do seem to prize accuracy above all. We want our beliefs to be accurate—to align with what is really true about the world—and we know that science is a reliable guide to accuracy. But this desire to be accurate conflicts with other motives, some of them unconscious. People hold beliefs to protect important values, for example. Individuals who think of nature as sacred may perceive genetic modification as morally wrong, regardless of its safety or utility. People also hold beliefs that are rooted in their emotions. A flu pandemic that can cause widespread death among the innocent may cause feelings of fear and helplessness. One way to cope with those emotions is to belittle warnings of a pandemic as improbable.

In reconciling our rational and irrational motives for belief, we have become good at kidding ourselves. Because we want to see ourselves as rational beings, we find reasons to maintain that our beliefs *are* accurate. One or two contrarians are sufficient to convince us that the science is "controversial" or "unsettled." If people knew that other motives might compromise the accuracy of their beliefs, most would probably try to be on their guard.

Asking science teachers to impart enough content to understand all the issues may be unrealistic, but they might be able to improve people's appreciation for the accuracy of scientific knowledge. Through the study of the history of science, students might gain an understanding both of their own motivations for belief and of science as a method of knowing. If a student understands how a medieval worldview could have made a geocentric theory of the solar system seem correct, it is a short step to seeing similar influences in oneself.

Science history can also help students understand why scientific knowledge grows ever more accurate. It is easy for a nonscientist to dismiss an unpleasant conclusion as controversial on the grounds that scientists constantly change their minds: "First they say chocolate is bad for us, then it's good … they can't decide anything." By studying how new observations led to the revision of important theories, however, students see that science is not about immutable laws but provisional explanations that get revised when a better one comes along. They also see that scientists' readiness to change their beliefs to align with data is a source of great strength, not weakness, and why near consensus on issues such as global warming or vaccine safety is so impressive.

Science may not be the only way of organizing and understanding our experience, but for accuracy it fares better than religion, politics and art. That's the lesson. SA

Daniel T. Willingham is professor of psychology at the University of Virginia and is author of *Why Don't Students Like School?* (Jossey-Bass, 2009).

Illustration by Jeffrey Decoster

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climate

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The world is running out of time to avert dangerous warming and keep the rise in global temperature below two degrees Celsius. Although scientists are still debating some specifics of climate change, such as whether warming has already caused Antarctica to lose mass (*page 34*), they clearly agree that global warming is real and that we humans are the culprit. In spite of this scientific consensus, some—including the U.S. president and many Republican representatives in Congress—continue to fiercely deny the existence of climate change and humanity's role in causing it. Their claims are misleading—they cite facts out of context, conjure up their own baseless theories about how the climate works or rely on conspiracy theories. Basic science and mountains of evidence, however, expose the flaws in their arguments (*pages 46* and *26*). When the U.S. finally comes to terms with climate change, it will still need to decide the best way to cut carbon pollution—which Naomi Oreskes argues will ultimately depend on both the marketplace and government (*page 40*).

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7

ANSWERS TO CLIMATE CONTRARIAN NONSENSE

EVIDENCE FOR HUMAN INTERFERENCE WITH EARTH'S CLIMATE CONTINUES TO ACCUMULATE

By John Rennie

Illustration by Alison Seiffer

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MOST OF DONALD J. TRUMP'S WORDS AND ACTIONS CONCERNING CLIMATE change have pointed toward his unambiguous disbelief in it. As a presidential candidate and earlier, he repeatedly called global warming an "expensive hoax," a Chinese plot to undermine U.S. manufacturing and "a very, very expensive tax." As president, he has repeatedly suggested he will withdraw the U.S. from the Paris climate accord aimed at limiting carbon emissions. To head the Department of Energy and the Environmental Protection Agency, he picked Rick Perry and Scott Pruitt respectively, both of whom have questioned the role of carbon dioxide in climate change. Trump's nominees for secretary of agriculture, Sam Clovis, and director of NASA, Jim Bridenstine, have similar views, as do many other appointees to less prominent federal offices.

Yet during his first presidential debate with Democratic candidate Hilary Clinton, he denied calling climate change a Chinese hoax. And when reporters have directly asked White House press secretaries whether Trump denies global warming is real, they have skirted the question. The administration seems to want its official stance on the issue to be undeclared and skeptical.

Skepticism was the intellectual virtue that U.S. Senator James R. Inhofe (R–Okla.) said he was championing in November 2009, with the United Nations Global Warming Conference in Copenhagen fast approaching, when he took to the floor of the Senate and proclaimed it to be "The Year of the Skeptic." Had the senator's speech marked a new commitment to dispassionate, rational inquiry, a respect for scientific thought and a well-grounded doubt in ghosts, astrology, creationism and homeopathy, it might have been cause for cheer. But Inhofe had a narrower definition of skeptic in mind: he meant "standing up and exposing the science, the costs and the hysteria behind global warming alarmism."

Within the community of scientists and others concerned about anthropogenic climate change, those whom Inhofe called skeptics are more commonly termed contrarians, naysayers and denialists. Not everyone who questions climate change science fits that description, of course—some people are genuinely unaware of the facts or honestly disagree about their interpretation. What distinguishes the true naysayers is an unwavering dedication to denying the need for action on the problem, often with weak and long-disproved arguments about supposed weaknesses in the science behind global warming.

What follows is only a partial list of the contrarians' bad arguments and some brief rebuttals of them.

IN BRIEF

Naysayers of climate change, including members of Congress and President Donald Trump, often use weak and long-disproved arguments about alleged holes in the science behind global warming.
Human activity is by far the largest source of carbon dioxide pumping into the atmosphere. The vast majority of climate scientists agree that this contribution is heating the planet and will cause undeniable impact on all ecosystems on Earth.
No other explanation—not solar variations or a giant global conspiracy orchestrated by scientists—can account entirely for the fact that the planet is warming and CO_2 from human activity is the cause. Multiple lines of evidence, from ice cores to tree rings, support this conclusion.

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FORESTS REMOVE atmospheric CO_2 and offset the nonhuman releases of CO_2. Human activity, combined with forest clearing (*shown here*), negates this process, however.

Claim 1: Anthropogenic carbon dioxide can't be changing climate, because CO_2 is only a trace gas in the atmosphere and the amount produced by humans is dwarfed by the amount from volcanoes and other natural sources. Water vapor is by far the most important greenhouse gas, so changes in CO_2 are irrelevant.

Although CO_2 makes up only 0.04 percent of the atmosphere, that small number says nothing about its significance in climate dynamics. Even at that low concentration, CO_2 absorbs infrared radiation and acts as a greenhouse gas, as physicist John Tyndall demonstrated in 1859. Chemist Svante Arrhenius went further in 1896 by estimating the impact of CO_2 on the climate; after painstaking hand calculations, he concluded that doubling its concentration might cause almost six degrees Celsius of warming—an answer not much out of line with recent, far more rigorous computations.

Contrary to the contrarians, human activity is by far the largest contributor to the observed increase in atmospheric CO_2. According to the Global Carbon Project, anthropogenic CO_2 amounts to about 35 billion tons annually—more than 130 times as much as volcanoes produce. True, 95 percent of the releases of CO_2 to the atmosphere are natural, but natural processes such as plant growth and absorption into the oceans pull the gas back out of the atmosphere and almost precisely offset them, leaving the human additions as a net surplus. Moreover, several sets of experimental measurements, including analyses of the shifting ratio of carbon isotopes in the air, further confirm that fossil-fuel burning and deforestation are the primary reasons that CO_2 levels have risen 40 percent since 1832, from 284 parts per million (ppm) to more than 400 ppm—a remarkable jump to the highest levels seen in millions of years.

Contrarians frequently object that water vapor, not CO_2, is the most abundant and powerful greenhouse gas; they insist

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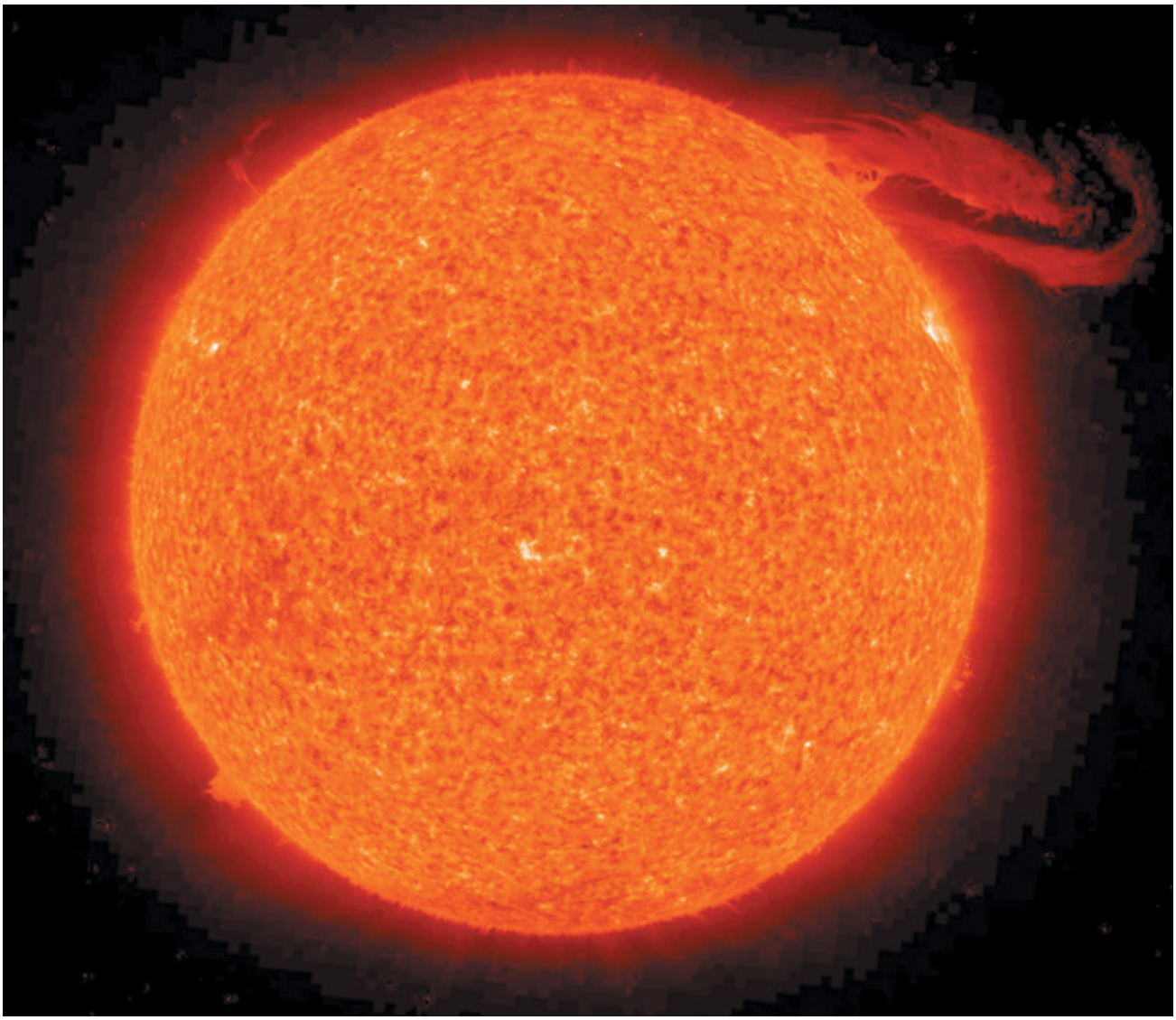

NASA

CLIMATE CONTRARIANS argue that variation in solar energy reaching the planet is behind global warming. But human influence has a measurably stronger effect on climate.

that climate scientists routinely leave it out of their models. The latter is simply untrue: from Arrhenius on, climatologists have incorporated water vapor into their models. In fact, water vapor is why rising CO_2 has such a big effect on climate. CO_2 absorbs some wavelengths of infrared that water does not, so it independently adds heat to the atmosphere. As the temperature rises, more water vapor enters the atmosphere and multiplies CO_2's greenhouse effect; the Intergovernmental Panel on Climate Change notes that water vapor may "approximately double the increase in the greenhouse effect due to the added CO_2 alone."

Nevertheless, within this dynamic, the CO_2 remains the main driver (what climatologists call a "forcing") of the greenhouse effect. As NASA climatologist Gavin Schmidt has explained, water vapor enters and leaves the atmosphere much more quickly than CO_2 and tends to preserve a fairly constant level of relative humidity, which caps off its greenhouse effect. Climatologists therefore categorize water vapor as a feedback rather than a forcing factor. (Contrarians who don't see water vapor in climate models are looking for it in the wrong place.)

Because of CO_2's inescapable greenhouse effect, contrarians holding out for a natural explanation for current global warming need to explain why, in their scenarios, CO_2 is not compounding the problem.

Claim 2: The alleged "hockey stick" graph of temperatures over the past 1,600 years has been disproved. It doesn't even acknowledge the existence of a "medieval warm period" around A.D. 1000 that was hotter than today is. Therefore, global warming is a myth.

It is hard to know which is greater: contrarians' overstatement of the flaws in the historical temperature reconstruction from 1998 by Michael E. Mann and his colleagues or the ultimate insignificance of their argument to the case for climate change.

First, there is not simply one hockey-stick reconstruction of historical temperatures using one set of proxy data. Similar evi-

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dence for sharply increasing temperatures over the past couple of centuries has turned up independently while looking at ice cores, tree rings and other proxies for direct measurements, from many locations. Notwithstanding their differences, they corroborate that the planet has been getting sharply warmer.

A 2006 National Research Council review of the evidence concluded "with a high level of confidence that global mean surface temperature was higher during the last few decades of the 20th century than during any comparable period during the preceding four centuries"—which is the section of the graph most relevant to current climate trends. The report placed less faith in the reconstructions back to A.D. 900, although it still viewed them as "plausible." Medieval warm periods in Europe and Asia with temperatures comparable to those seen in the 20th century were therefore similarly plausible but might have been local phenomena: the report noted "the magnitude and geographic extent of the warmth are uncertain." And a research paper by Mann and his colleagues seems to confirm that the Medieval Warm Period and the "Little Ice Age" between 1400 and 1700 were both caused by shifts in solar radiance and other natural factors that do not seem to be happening today.

THREE OF THE 15 HOTTEST YEARS ON RECORD HAVE ALL OCCURRED SINCE 2000.

After the NRC review was released, another analysis by four statisticians, called the Wegman report, which was not formally peer-reviewed, was more critical of the hockey-stick paper. But correction of the errors it pointed out did not substantially change the shape of the hockey-stick graph. In 2008 Mann and his colleagues issued an updated version of the temperature reconstruction that echoed their earlier findings.

But hypothetically, even if the hockey stick was busted … What of it? The case for anthropogenic global warming originally came from studies of climate mechanics, not from reconstructions of past temperatures seeking a cause. Warnings about current warming trends came out years before Mann's hockey-stick graph. Even if the world were incontrovertibly warmer 1,000 years ago, it would not change the fact that the recent rapid rise in CO_2 explains the current episode of warming more credibly than any natural factor does—and that no natural factor seems poised to offset further warming in the years ahead.

Claim 3: Global warming stopped in 1998; Earth has been cooling since then.

This contrarian argument might be the most obsolete and unintentionally hilarious. Here's how it goes: 1998 was the world's warmest year according to the U.K. Met Office Hadley Center's records; the following decade was cooler; therefore, the previous century's global warming trend is over, right?

Anyone with even a glancing familiarity with statistics should be able to spot the weaknesses of that argument. Given the extended duration of the warming trend, the expected (and observed) variations in the rate of increase and the range of uncertainties in the temperature measurements and forecasts, a decade's worth of mild interruption is too small a deviation to prove a break in the pattern, climatologists say.

If a lull in global warming had continued for another decade, would that have vindicated the contrarians' case? Not necessarily, because climate is complex. For instance, Mojib Latif of the Leibniz Institute of Marine Sciences in Germany and his colleagues published a paper in 2008 that suggested ocean circulation patterns might cause a period of cooling in parts of the Northern Hemisphere, even though the long-term pattern of warming remained in effect. Fundamentally, contrarians who have resisted the abundant evidence that supports warming should not be too quick to leap on evidence that only hints at the opposite.

In any case, the claim that a "warming pause" disproved ongoing climate change became completely academic when 1998 stopped being the warmest year on record. That title now goes to 2014. In fact, as Climate Central notes, "13 of the 15 hottest years on record have all occurred since 2000."

Claim 4: The sun or cosmic rays are much more likely the real causes of global warming. After all, Mars is warming up, too.

Astronomical phenomena are obvious natural factors to consider when trying to understand climate, particularly the brightness of the sun and details of Earth's orbit because those seem to have been major drivers of the ice ages and other climate changes before the rise of industrial civilization. Climatologists, therefore, do take them into account in their models. But in defiance of the naysayers who want to chalk the recent warming up to natural cycles, there is insufficient evidence that enough extra solar energy is reaching our planet to account for the observed rise in global temperatures.

The IPCC has noted that between 1750 and 2005, the radiative forcing from the sun increased by 0.12 watt per square meter—less than a tenth of the net forcings from human activities (1.6 W/m^2). The largest uncertainty in that comparison comes from the estimated effects of aerosols in the atmosphere, which can variously shade Earth or warm it. Even granting the maximum uncertainties to these estimates, however, the increase in human influence on climate exceeds that of any solar variation.

Moreover, remember that the effect of CO_2 and the other greenhouse gases is to amplify the sun's warming. Contrarians looking to pin global warming on the sun can't simply point to any trend in solar radiance: they also need to quantify its effect and explain why CO_2 does not consequently become an even more powerful driver of climate change. (And is what weakens the greenhouse effect a necessary consequence of the rising solar influence or an ad hoc corollary added to give the desired result?)

Contrarians therefore gravitated toward work by Henrik Svensmark of the Technical University of Denmark, who argues that the sun's influence on cosmic rays needs to be considered. Cosmic rays entering the atmosphere help to seed the formation of aerosols and clouds that reflect sunlight. In Svensmark's theory, the high solar magnetic activity over the past 50 years has shielded Earth from cosmic rays and allowed exceptional heating, but now that the sun is more magnetically quiet again, global warming will reverse. Svensmark claims that, in his model, temperature changes correlate better with cosmic-ray levels and solar magnetic activity than with other greenhouse factors.

Svensmark's theory failed to persuade most climatologists, however, because of weaknesses in its evidence. In particular, there do not seem to be clear long-term trends in the cosmic-ray influxes or in the clouds that they are supposed to form, and his

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ELEVATED CO_2 makes oceans acidic, which could have irreversible harmful effects on coral reefs, such as coral bleaching (*shown here*).

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model does not explain (as greenhouse explanations do) some of the observed patterns in how the world is getting warmer (such as that more of the warming occurs at night). For now, at least, cosmic rays remain a less plausible culprit in climate change.

And the apparent warming seen on Mars? It is based on a very small base of measurements, so it may not represent a true trend. Too little is yet known about what governs the Martian climate to be sure, but a period when there was a darker surface might have increased the amount of absorbed sunlight and raised temperatures.

Claim 5: Climatologists conspire to hide the truth about global warming by locking away their data. Their so-called consensus on global warming is scientifically irrelevant because science isn't settled by popularity.

It is virtually impossible to disprove accusations of giant global conspiracies to those already convinced of them (can anyone prove that the Freemasons and the Roswell aliens aren't involved, too?). Let it therefore be noted that the magnitude of this hypothetical conspiracy would need to encompass many thousands of uncontroversial publications and respected scientists from around the world, stretching back through Arrhenius and Tyndall for almost 150 years. A conspiracy would have to be so powerful that it has co-opted the official positions of dozens of scientific organizations, including the U.S. National Academy of Sciences, the U.K.'s Royal Society, the American Association for the Advancement of Science, the American Geophysical Union, the American Institute of Physics and the American Meteorological Society.

If there were a massive conspiracy to defraud the world on climate (and to what end?), surely the thousands of e-mails and other files stolen from the University of East Anglia's Climatic Research Unit in England and distributed by hackers in 2009 would bear proof of it. None did. Most of the few statements from those e-mails that critics claimed as evidence of malfeasance had more innocent explanations that make sense in the context of scientists conversing privately and informally. If any of the scientists involved manipulated data dishonestly or thwarted Freedom of Information requests, it would have been deplorable; however, there is no evidence that happened. What is missing is any clear indication of a widespread attempt to falsify and coordi-

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nate findings on a scale that could hold together a global cabal or significantly distort the record on climate change.

Climatologists are often frustrated by accusations that they are hiding data or the details of their models because, as NASA's Schmidt points out, much of the relevant information is in public databases or otherwise accessible—a fact that contrarians conveniently ignore when insisting that scientists stonewall their requests. (And because nations differ in their rules on data confidentiality, scientists are not always at liberty to comply with some requests.) If contrarians want to deal a devastating blow to global warming theories, they should use the public data and develop their own credible models to demonstrate sound alternatives.

RESPONSIBLE ACTION ON CLIMATE CHANGE IS WHAT THE CONTRARIANS SEEM MOST INTERESTED IN DENYING.

Yet that rarely occurs. In 2004 historian of science Naomi Oreskes published a well-known analysis of the peer-reviewed literature on global warming, "The Scientific Consensus on Climate Change." Out of 928 papers whose abstracts she surveyed, she wrote, 75 percent explicitly or implicitly supported anthropogenic global warming, 25 percent were methodological or otherwise took no position on the subject—and none argued for purely natural explanations. Notwithstanding some attempts to debunk Oreskes's findings that eventually fell apart, her conclusion stands.

Oreskes's work does not mean that all climate scientists agree about climate change—obviously, some do not (although they are very much a minority). Rather the meaningful consensus is not among the scientists but within the science: the overwhelming predominance of evidence for greenhouse-driven global warming that cannot easily be overturned even by a few contrary studies.

Claim 6: Climatologists have a vested interest in raising the alarm because it brings them money and prestige.

If climate scientists are angling for more money by hyping fears of climate change, they are not doing so very effectively. According to the U.S. Government Accountability Office, between 1993 and 2014, federal spending on climate change research, technology, international assistance and adaptation rose from $2.4 billion to $11.6 billion. (An additional $26.1 billion was also allocated to climate change programs and activities by the economic stimulus package of the American Recovery and Reinvestment Act in 2009. Total federal nondefense spending on research in 2014 exceeded $65 billion.) Yet the scientific research share of that money fell sharply throughout that period: most of the budgeted money went to energy conservation projects and other technology programs. Climatologists' funding therefore stayed almost flat, whereas others, including those in industry, benefited handsomely. Surely the Freemasons could do better than that.

Claim 7: Technological fixes, such as inventing energy sources that don't produce CO_2 or geoengineering the climate, would be more affordable, prudent ways to address climate change than reducing our carbon footprint.

Critics of standard policy responses to climate change have often seemed to imply that environmentalists are obsessed with regulatory reductions in CO_2 emissions and uninterested in technological solutions. That interpretation is at best bizarre: such innovations in energy efficiency, conservation and production are exactly what caps or levies on CO_2 are meant to encourage.

The relevant question is whether it is prudent for civilization to defer curbing or reducing its CO_2 output before such technologies are ready and can be deployed at the needed scale. The most common conclusion is no. Remember that as long as CO_2 levels are elevated, additional heat will be pumped into the atmosphere and oceans, extending and worsening the climate consequences. As NASA climatologist James Hansen has pointed out, even if current CO_2 levels could be stabilized overnight, surface temperatures would continue to rise by 0.5 degree C over the next few decades because of absorbed heat being released from the ocean. The longer we wait for technology alone to reduce CO_2, the faster we will need for those solutions to pull CO_2 out of the air to minimize the warming problems. Minimizing the scope of the challenge by restricting the accumulation of CO_2 only makes sense.

Moreover, climate change is not the only environmental crisis posed by elevated CO_2: it also makes the oceans acidic, which could have irreversibly harmful effects on coral reefs and other marine life. Only the immediate mitigation of CO_2 release can contain those losses.

Much has already been written on why schemes for geoengineering—altering Earth's climate systems by design—seem ill advised except as a desperate last-chance strategy for dealing with climate change. The more ambitious proposals involve largely untested technologies, so it is unclear how well they would achieve their desired purpose; even if they did curb warming, they might cause other significant environmental problems in the process. Methods that did not remove CO_2 from the air would have to be maintained in perpetuity to prevent drastic rebound warming. And the governance of the geoengineering system could become a political minefield, with nations disagreeing about what the optimal climate settings should be. And of course, as with any of the other technological solutions, reducing the emission and accumulation of CO_2 in the atmosphere first would only make any geoengineering solution easier.

All in all, counting on future technological developments to solve climate change rather than engaging with the problem straightforwardly by all available means, including regulatory ones, seems like the height of irresponsibility. But then again, responsible action on climate change is what the contrarians seem most interested in denying. SA

John Rennie is the former editor in chief of *Scientific American*.

MORE TO EXPLORE

Global-Scale Temperature Patterns and Climate Forcing over the Past Six Centuries. Michael E. Mann, Raymond S. Bradley and Malcolm K. Hughes in *Nature,* Vol. 392, pages 779–787; April 23, 1998.

Climate Change 2014: Synthesis Report. Working Groups I, II and III of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2014. Available at www.ipcc.ch/report/ar5/syr

The Consensus on Anthropogenic Global Warming Matters. James L. Powell in *Bulletin of Science, Technology and Society,* Vol. 36, No. 3; 2016. Published online May 24, 2017.

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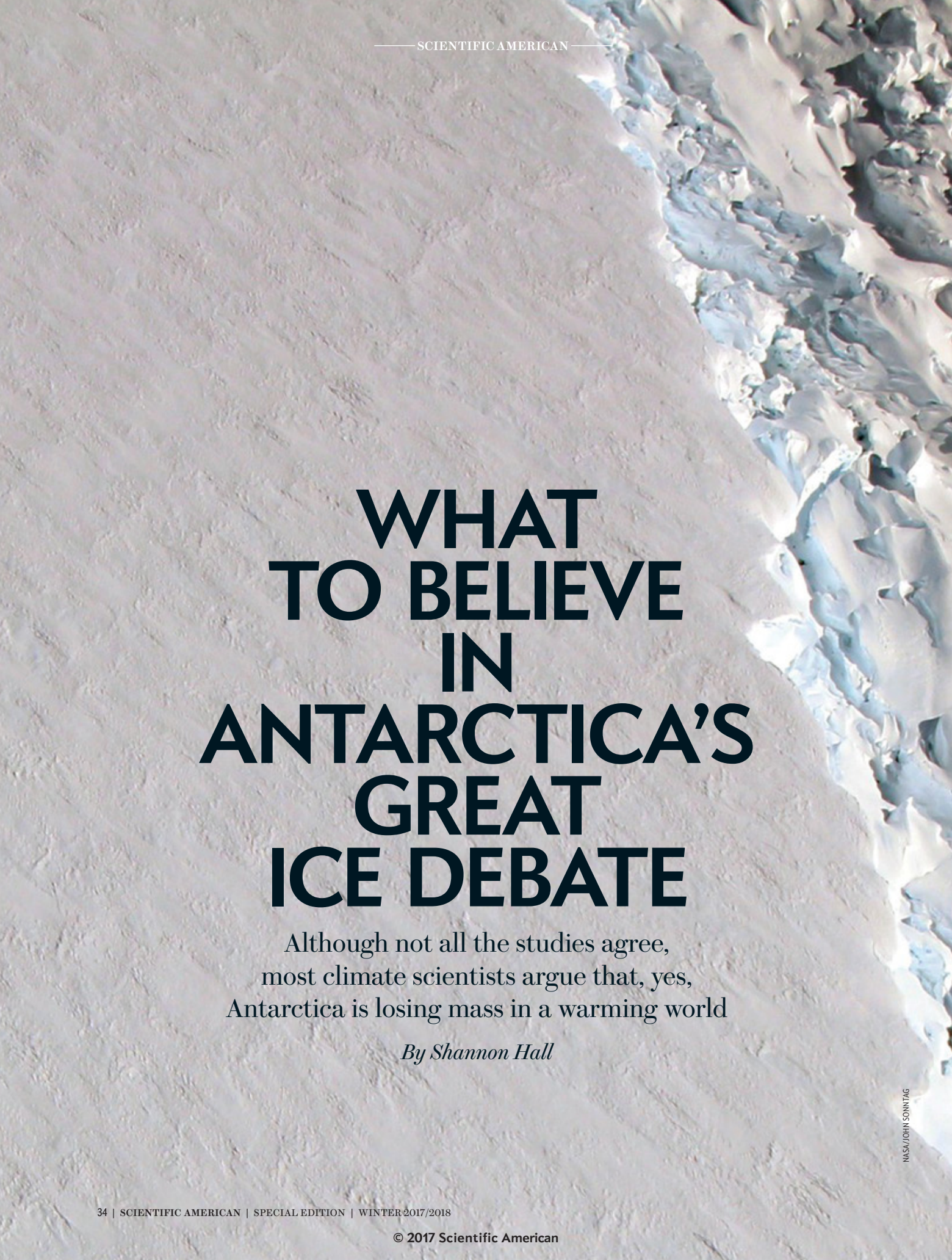

WHAT TO BELIEVE IN ANTARCTICA'S GREAT ICE DEBATE

Although not all the studies agree, most climate scientists argue that, yes, Antarctica is losing mass in a warming world

By Shannon Hall

NASA/JOHN SONNTAG

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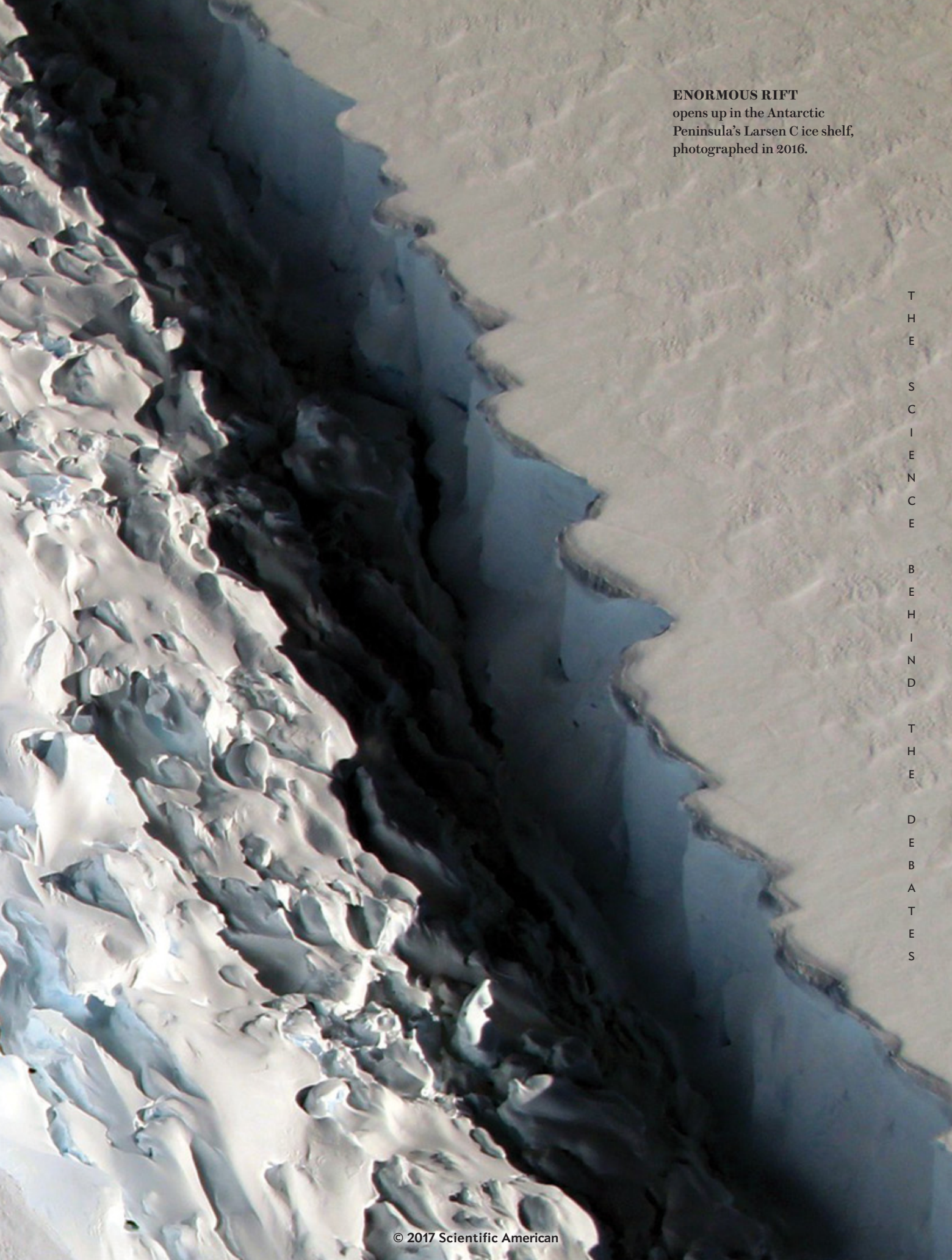

ENORMOUS RIFT
opens up in the Antarctic Peninsula's Larsen C ice shelf, photographed in 2016.

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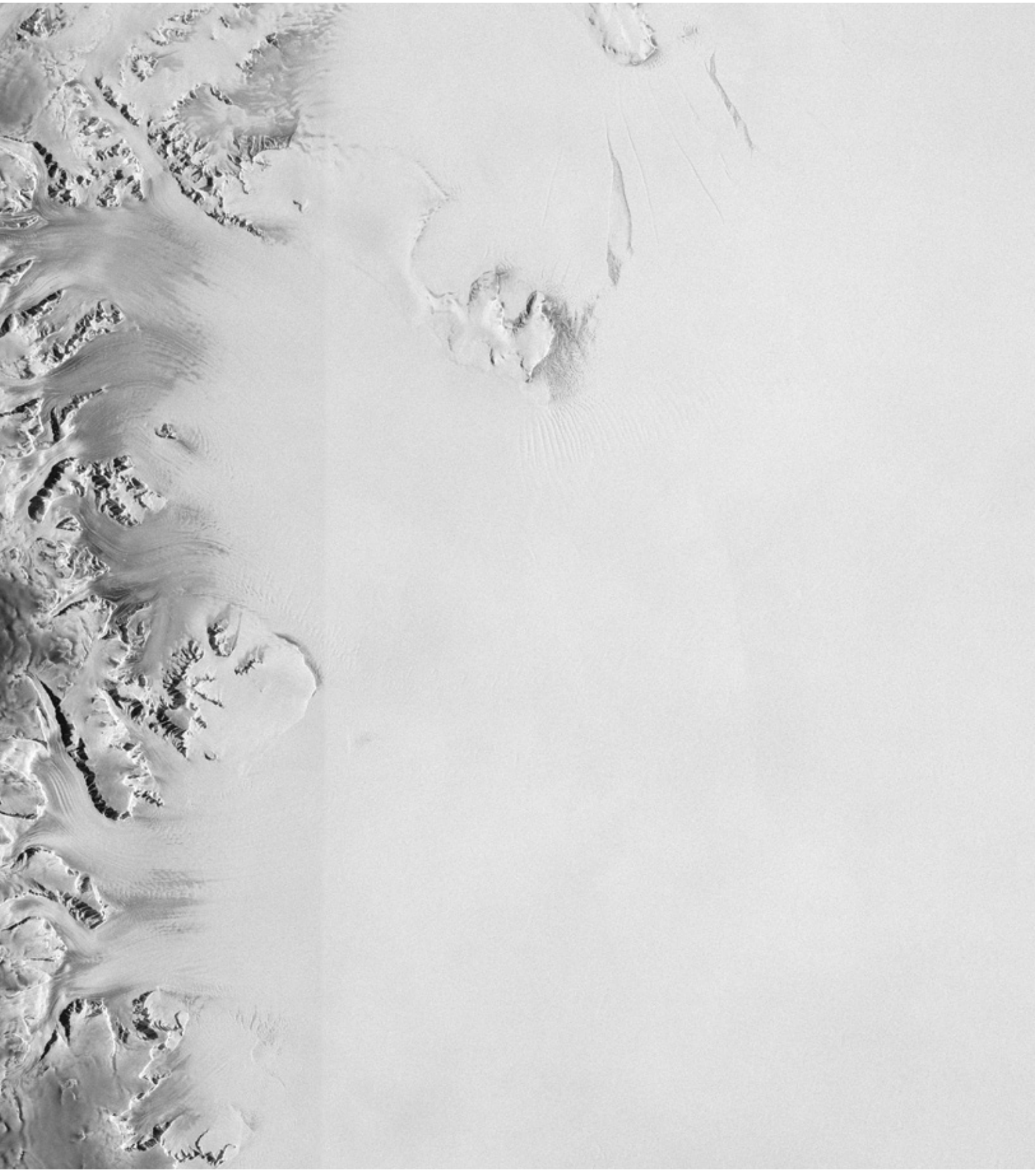

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CHUNK OF ICE more than twice the size of Luxembourg broke off the Larsen C ice shelf in July 2017, spawning one of the largest icebergs on record.

OUR FATE IS TIED TO A frozen desert at the bottom of the world. Should Antarctica's ice sheets dissolve, sea levels would rise dramatically—enough to flood the world's great coastal megalopolises from New York to Shanghai and push millions of people inland. But determining just how the vast and frigid continent is currently responding to a warming world has been a challenge. In West Antarctica the story is relatively clear. The floating platforms of ice that ring the coast are thinning, glaciers are surging toward the sea, meltwater is flowing across the surface, fast-growing moss is turning the once shimmering landscape green and a massive iceberg the size of Delaware broke off into the ocean in July of 2017. But in East Antarctica, where rising temperatures have caused increased humidity and thus more snowfall, the story takes an unexpected turn.

Most scientists agree that East Antarctica—unlike its western counterpart—is gaining mass in the form of snowfall or ice, or both. But how much? And is it enough to counterbalance West Antarctica's accelerating losses? A study published in *Geophysical Research Letters* in May 2017 by Alba Martin-Español of the University of Bristol in England and his colleagues suggests the gains in East Antarctica are so small that the continent is losing mass overall. This is just one in a long line of stud-

IN BRIEF

In 2015 a study was published claiming that East Antarctica is in fact gaining mass, contrary to the majority of studies conducted thus far.
The research, while sound, sparked controversy and was quickly picked up by climate change deniers and conservative news outlets.
Most studies show that, overall, the glaciers on the planet are shrinking in a warming climate. In fact, early data show that the loss of ice in 2016 could overshadow any gains that may have happened or will happen.

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ies that disagree with rather controversial findings published in 2015 in the *Journal of Glaciology,* which suggested that Antarctica is gaining mass. That study sparked a dizzying debate—but one that will ultimately help glaciologists grasp just what is happening in East Antarctica and push scientists to consider how to handle contentious results in a warming world.

There is no doubt that the 2015 study, led by Jay Zwally, a glaciologist at NASA's Goddard Space Flight Center, flew in the face of previous research and even assertions made by the United Nations Intergovernmental Panel on Climate Change (IPCC). Zwally's study remains the only one to firmly conclude that Antarctica is growing. "That in itself doesn't mean something is wrong" with the result, says Jonathan Bamber, a glaciologist at Bristol, who co-authored the recent paper led by Martin-Español. Nevertheless, Bamber and many others agree the dominant consensus should still prevail—and that might be especially true in a field as highly politicized as climate change.

Zwally's results spread like wildfire across many conservative news outlets—including Fox News, Breitbart News and *The Daily Express*—which hailed it as another sign that the dangers of climate change have been exaggerated. Although climate scientists often see such news stories, they still worry about the dangers these might cause in today's political climate. That is why Theodore Scambos, a senior research scientist at the National Snow and Ice Data Center, decided to take matters into his own hands. He had just boarded a flight to attend a meeting of the American Polar Society when he overheard a neighboring passenger claim that Antarctica was gaining mass. "I thought, 'Well, that's it—we have to say something because it's not,'" he recalls.

So Scambos and his Goddard colleague Christopher Shuman wrote a rebuttal to Zwally's paper. Using NASA and European Space Agency satellites, the 2015 study had measured the changing height of the ice sheet and determined that East Antarctica was ballooning upward by roughly 1.59 centimeters a year (at least from 1992 to 2001 and from 2003 to 2008). Although many agree East Antarctica is rising, Scambos and Shuman think the rate is much lower—and that the discrepancy arose from Zwally's technique. The satellites in his study fire lasers toward Earth. The beams reflect back at the satellite, allowing scientists to calculate the surface ice's height. But this technique is not perfect, and the beams require careful calibration using a flat, unchanging "reference surface." For this, most scientists use well-understood regions on the ice sheet itself. But Zwally and his team used stretches of the Southern Ocean that are exposed between cracks in the ice, and Scambos worries that these pools are not as still as they seem. He argues that such surfaces can easily form a new layer of ice or even frost flowers—rare (and gorgeous) ice crystals that grow upward from the sea. This would make the reference surface move, an effect that could interfere with the data.

Even if other scientists could accept Zwally's measurements of ice sheet inflation, they would quickly run into what many would see as a second hiccup in his study. To translate the change in height (and therefore volume) into a change in mass, scientists must assume a certain density. The question is: Just what is rising? Is it snow or ice? Zwally contends it is ice, and argues that at the end of the last ice age, roughly 10,000 years ago, the amount of snowfall doubled. This would mean that it has been compacting into solid ice for millennia and continues to do so today. Most other scientists, however, do not agree that this is still going on now and argue that any increase in the ice sheet's height is from added snowfall alone. In this case, the density of snow would be the right number to use. The difference is critical: a rise of one centimeter of snow across all of East Antarctica is the equivalent of 35 billion metric tons, but a rise of one centimeter of ice is the equivalent of 92 billion metric tons. Using the latter (plus a huge rise in the height of the ice sheet), Zwally's study finds that East Antarctica has gained roughly 147 billion metric tons a year.

But other studies disagree. Take the latest study published by Martin-Español, Bamber and their colleagues, which incorporates a different approach that does not require a numerical density model. Instead the team used data from a satellite called the Gravity Recovery and Climate Experiment (GRACE), which measures changes in Earth's gravitational field that are caused by changes in mass. They found that the gains in East Antarctica were about three times smaller than those suggested in Zwally's 2015 study. From 2003 to 2013 they measured an annual rise of roughly five millimeters, which they think is equivalent to 57 billion metric tons of fresh new snow every year. Because this gain is

SEA ICE in McMurdo Sound, Antarctica, splits to reveal long passages that marine life can travel through.

PRECEDING PAGES: ESA, CONTAINING COPERNICUS SENTINEL DATA FROM 2017; THIS PAGE: NORBERT WU *Getty Images*

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lower than the losses occurring in West Antarctica, they conclude the entire continent has made a net contribution to sea-level rise. "It's the kind of integrated study that we absolutely need to understand how the planet works and how it's changing," says Robin Bell, a polar scientist at the Lamont-Doherty Earth Observatory at Columbia University.

Zwally, however, remains confident in his numbers. "It's definitely a bit of a contentious issue—not just polite conversation," says Scambos, who continues to worry about the harm a dispute like this can do in a time when many science fields are increasingly subject to political polarization. To see causes for concern, one need only look as far as the infamous—and now retracted—paper published in 1998 that suggested the combined measles, mumps and rubella vaccine in children raised the chances for autism. Despite the retraction, the paper helped to fuel a worldwide fear of vaccines and continues to be referenced to this day. Similarly, Zwally's 2015 study—though scientifically sound—is an outlier cherry-picked by conservative news outlets to advance their denialist positions. In summer of 2017 Prison Planet, one of far-right radio host Alex Jones's Web sites, offered it as evidence that President Donald Trump made the correct decision in leaving the Paris agreement on fighting climate change. As such, Scambos thinks Zwally's paper "has been a real disservice to the science community."

Perhaps the light at the end of the tunnel is that the debate has sparked conversation about how to handle such controversial studies. "By and large, the primary responsibility of the scientists is to present what they believe to be the most reliable and accurate science," Bamber says. "How the media interprets that can often be out of [scientists'] control.... Having said that, I think we also have a responsibility to ensure that we communicate the messages in a clear and unambiguous way." Zwally notes that he was vigilant about this in 2015. "When our paper came out, I was very careful to emphasize that this is in no way contradictory to the findings of the IPCC report or conclusions that climate change is a serious problem that we need to do something about," he says. He was referring to the panel's 2013 report, which stated not only that Antarctica was losing mass but that the process was accelerating. Zwally knew Antarctica would contribute to sea-level rise in a warming world but simply did not agree that the effect had already kicked in. He was therefore less than thrilled to see the conservative media having a field day with his study.

Still, many argue the controversial results are a natural process within scientific study. If you shine a spotlight on almost any corner in science, you are bound to find disagreement. "That's the way that science has moved on since Archimedes, since Isaac Newton, since [Johannes] Kepler," says Andrew Shepherd, a polar scientist at the University of Leeds in England. "Everybody has a difference of opinion, and if they didn't—if everybody believed what had gone before—we wouldn't move forward."

At the end of the day many agree that Zwally's study—albeit an outlier—has pushed the science forward. It sparked reactions in the community, from rebuttals to new papers, which will likely help glaciologists across the globe eventually pin down just what is happening in East Antarctica. Shepherd, for example, is currently working on a review that will reconcile roughly 50 findings from the many techniques that have measured the ice mass balance, and will hopefully settle on an accurate average. That said, it might be a moot point. Zwally's study team claimed that if mass losses in West Antarctica continued to increase, it would only be a few decades before they overtook the gains in the east. Also, the team has additional, unpublished data showing the mass losses in West Antarctica have not only increased, but have tripled—at least from 2009 to 2012. Early data show 2016 might have been the tipping point at which losses in West Antarctica became so great that they equaled those gains in East Antarctica. That means Zwally's results might already be in agreement with others on the key point: this frigid land—one that holds the fate of much of humanity—is melting. SA

Shannon Hall is a freelance science journalist based in New Hampshire.

MORE TO EXPLORE

Constraining the Mass Balance of East Antarctica. Alba Martin-Español et al. in *Geophysical Research Letters,* Vol. 44, No. 9, pages 4168–4175; May 16, 2017.
Mass Gains of the Antarctic Ice Sheet Exceed Losses. H. Jay Zwally et al. in *Journal of Glaciology,* Vol. 61, No. 230, pages 1019–1036. Published online July 10, 2017.
Global Snow and Ice. The most current data available from the National Oceanic and Atmospheric Administration: www.ncdc.noaa.gov/sotc/global-snow

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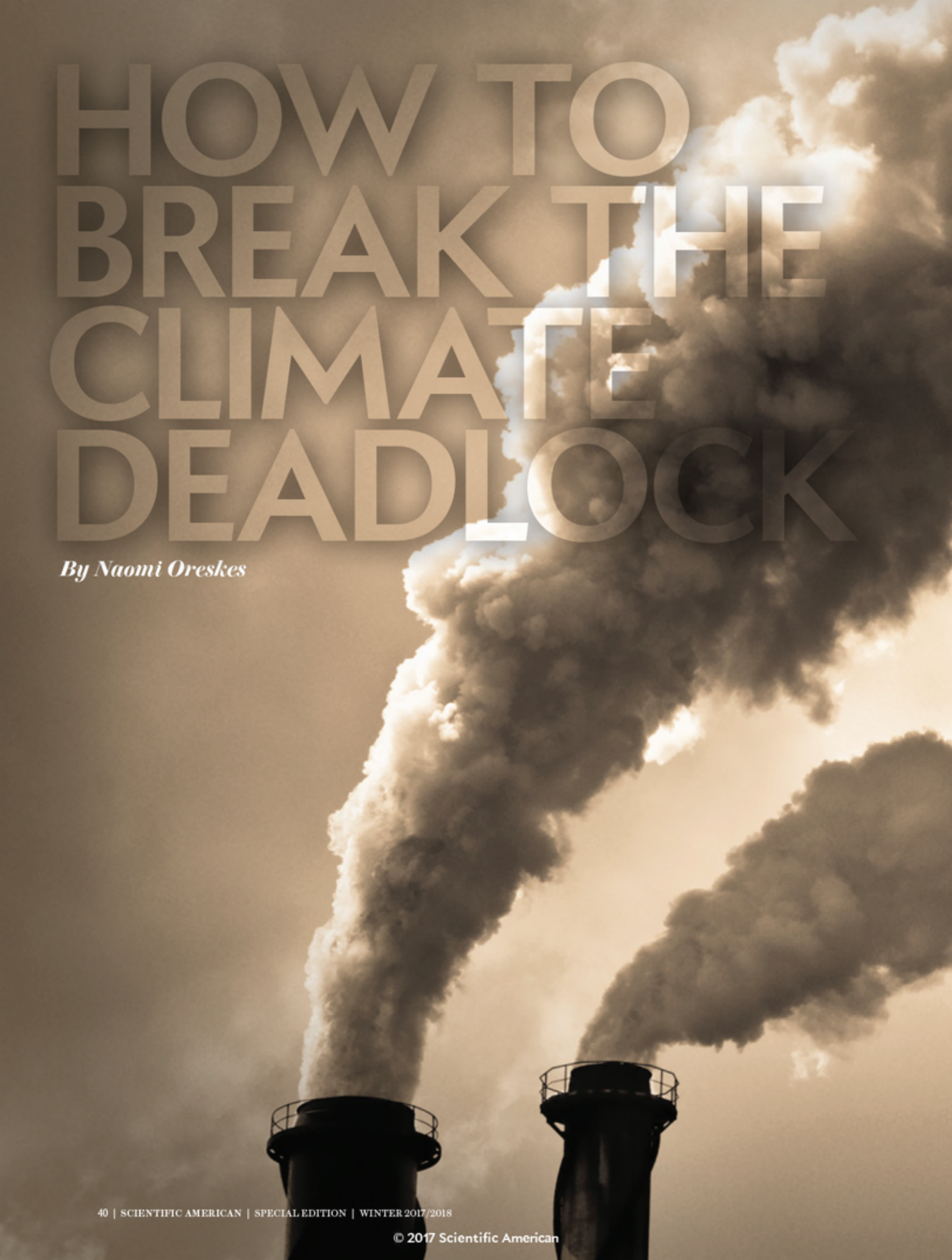
HOW TO BREAK THE CLIMATE DEADLOCK

By Naomi Oreskes



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WILL NATIONS EVER COME TOGETHER TO KEEP CLIMATE OUT OF THE SEVERE DANGER ZONE? The question looms like a cloud now that President Donald Trump has announced that the U.S. will withdraw from the Paris climate change accords—an international agreement to curb greenhouse gas emissions. But the nation's ambivalence about climate change long predates the last presidential election. A major reason is American conservatives' hostility to government intervention. If the U.S. and the world are to succeed in limiting disruptive climate change, the U.S. will have to give up the idea that free markets alone can adequately address climate change and embrace the reality that markets need help from governments.

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A U.N. TREATY IS EFFECTIVE only if signatory nations are prepared to follow suit with firm domestic policies, but American politicians have resisted action, afraid of paying a political price. The rejection of climate action is largely based on suspicion of big government, and an international treaty is government at its biggest. Yet making a substantial impact on something so fundamental as the sources of energy that drive our civilization is going to require billions (if not trillions) of dollars of investments and incentives that span diverse industries—the kinds of actions that the private sector has historically not made. If nations are ever going to put the brakes on climate change, the U.S. will have to overcome its aversion to government playing a major role.

UNREASONABLE RELIANCE ON FREE MARKETS

IT HAS LONG BEEN a maxim in American life that the government that governs best governs least. It was expressed in the weakness of the original Articles of Confederation, in the structure of the U.S. Constitution (designed to prevent the concentration of power) and at various times throughout U.S. history. In the 20th century it was an important element in reactions against federal labor standards, rural electrification and, especially, the New Deal, the spectacular government intervention that followed the equally spectacular market failure of the Great Depression. The deal empowered the federal government with substantive oversight of business, industry, and financial and labor markets. But the opponents of the New Deal never denied the fact of the Depression.

Opponents of an international treaty on climate change have allowed their hostility to government not only to lead them to discount the facts of climate change but also to spill over into conspiratorial thinking. In a 1992 speech Dixy Lee Ray, a former governor of Washington State and a former head of the U.S. Atomic Energy Commission, insisted that the agenda of the United Nations Framework Convention on Climate Change was to "bring about … world government with central planning by the United Nations." The flame she lit has burned brightly ever since. In his 2012 book Senator James Inhofe of Oklahoma accused climate scientists of being part of a liberal conspiracy to dismantle global capitalism and compared the Environmental Protection Agency to the Gestapo. Trump has a conspiracy theory of his own, calling climate change a hoax perpetrated by the Chinese.

Trump's views may be extreme, but they reflect a greater conservative mindset. In our 2010 book, *Merchants of Doubt,* Erik M. Conway and I show how conservative and libertarian think tanks have questioned the scientific evidence of climate change under the rubric of defending freedom, which they equate with laissez-faire capitalism: low rates of taxation, minimal regulation of business, and little or no government intervention in the marketplace. Social scientists have also shown a strong correlation between "free market ideology" and the beliefs that global climate change is not occurring, is not human-caused or will have positive effects—all positions that contradict the findings of the global scientific community.

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IN BRIEF

American rejection of climate action is based on suspicion of big government, often expressed as a threat to freedom.

Free markets will not solve climate change by themselves; they have failed to account for the damage done by carbon emissions to people and the environment.

A carbon tax, or emissions-trading system, could slow climate change, but government is needed to create those systems.

History shows that government is also needed to create and fund major technological innovations of the scale required to solve climate change. For that to happen, Americans will have to stop demonizing government.

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The main claim of politicians, lobbyists and CEOs who lead the charge to minimize the government's role in addressing climate change is that the world should rely on the marketplace to fix the problem. Greenhouse gas emissions are part of the world's economy, so if they are a problem, markets will respond, for instance, by offering technologies to prevent climate change or allow us to adapt to it.

In truth, however, energy markets do not account for the "external," or social, costs of using fossil fuels. These are not reflected in the price we pay at the pump, the wellhead or the electricity meter. For example, pollution from coal causes disease, damages buildings and contributes to climate change. When we buy electricity generated from coal, we pay for the electricity, but we do not pay for these other real, measurable costs.

INDUSTRY confers economic benefits but imposes social costs; science and government must balance the two.

In a properly functioning market, people pay the true cost of the goods and services they use. If I dump my garbage in your backyard, you are right to insist that I pay for that privilege, assuming you are willing to let me do it at all. And if you do not insist, you can be pretty sure that I will keep on dumping my garbage there. In our markets today, people are dumping carbon dioxide into the atmosphere without paying for that privilege. This is a market failure. To correct that failure, carbon emissions must have an associated cost that reflects the toll they take on people and the environment. A price on carbon encourages

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individuals, innovators and investors to seek alternatives, such as solar and wind power, that do not cause carbon pollution. When economist Hoesung Lee became the new head of the Intergovernmental Panel on Climate Change in 2015, he named carbon pricing as the world's top climate change priority.

Several countries and regions have implemented carbon prices. In British Columbia, a carbon tax has helped cut fuel consumption and carbon emissions without harming economic growth. To prevent taxes from rising overall, the government also lowered personal and corporate income taxes; the province now has the lowest personal income tax rate and one of the lowest corporate tax rates in Canada.

Another way to remedy the market failure of pollution is to create a trading system where people can buy the right to pollute—a right that they can use, save or sell. A company that can reduce its emissions more than the law requires can sell any unused credits, whereas a company that cannot meet the standards can buy credits until it figures out how to solve its pollution problem.

APPROPRIATE FORMS OF GOVERNMENT AUTHORITY ARE ESSENTIAL TO THE GUARANTEE OF LIBERTY. AS DISRUPTIVE CLIMATE CHANGE UNFOLDS, THEY WILL ALSO BE ESSENTIAL TO THE GUARANTEE OF LIFE AND THE PURSUIT OF HAPPINESS.

The idea of being able to buy the right to pollute offends many people, but properly implemented, emissions trading can work. In 1990 Congress passed, by a wide margin, a set of amendments to the Clean Air Act that implemented trading in sulfur dioxide emissions to reduce acid rain. The program was highly successful: over the ensuing decade emissions were cut by more than 50 percent. In 1993 California followed this example and implemented the Regional Clean Air Incentives Market to reduce air pollution in southern California. The air in Los Angeles is far cleaner today than it was 30 years ago, but hardly anyone knows that this was achieved to a substantial degree through emissions trading. China has been experimenting with regional emissions trading for several years and will soon make the system national.

The essential idea behind both emissions trading or carbon taxes is to harness the power of market forces. Many business leaders prefer emissions trading over taxation because once the system is in place, it enables a good deal of freedom and flexibility. But the key phrase here is "once in place." An emissions-trading system, or a tax, has to be created, and that does not happen by the "invisible hand" of the marketplace. It happens through government action. Which brings us back to the role of government and the aim of the U.N. Conference of the Parties talks.

TECHNOLOGIES WAIT FOR SCALE

SOME PEOPLE, pointing to the recent rapid drop in the cost of solar power, argue that the market is responding and thus proves that we can solve climate change without Paris, without a big international treaty or even without government intervention at all. Others say that if we just implement a carbon tax, the market will do the rest. Neither position captures the whole story.

To stop climate change, we need a new energy system. This means large-scale renewable power, coupled with dramatic increases in energy efficiency, demand management and energy storage. Solar and wind power work and in many domains are now cost-competitive, but they are not at the scale needed to replace enough fossil-fuel power plants to stop the ongoing rise in atmospheric CO_2 levels. After half a century of heavy and sustained public investment, nuclear power remains costly and controversial, and we still lack an accepted means of nuclear waste disposal. Carbon capture and storage—which collects emissions and puts them underground—is a great idea but has yet to be implemented.

A price on carbon will push demand in the right direction, but it needs to be reinforced by the pull of public investment in innovation. The most likely way we will get the innovation we need, at the scale we need, in the time frame we need and at a retail price that people can afford, is if the public sector plays a significant role.

It is possible that the market will bring us a technological breakthrough on climate change. But history suggests that this would be a long shot—even with a hefty price on carbon—because not one of the major technological developments of the 20th century was produced by the private sector working alone. Entrepreneurs such as Thomas Edison and George Westinghouse developed electricity, but it took the federal government to build the delivery systems that brought it to the lion's share of Americans. The same is true of telephone service. The federal government, starting with President Dwight Eisenhower, was needed to build an interstate highway system. Nuclear power was not a response to market demand: the U.S. government wanted to prove that the destructive power unleashed at Hiroshima and Nagasaki could have a constructive use. Former vice president Al Gore may not have invented the Internet, but the U.S. military did, as a technology under the Defense Advanced Research Projects Agency.

Gore did, however, help draft and pass the legislation that eventually released the Internet as a civilian technology that the private sector could commercialize and sell to millions of customers. The federal government developed digital computers, satellite communications, weather forecasting and the global positioning systems that tell mobile phones where we are. These transformative technologies were all created as public-private partnerships, more often than not with the government as lead partner. And they all took sustained effort over decades, the kind of effort for which the private sector has little stomach. A government pull is needed to develop climate solutions that, like the Internet, can be further advanced and marketed by the private sector. ARPA-E (Energy), an agency modeled after DARPA, is funding research in these areas, but its budget is peanuts. Its 2017 fiscal year request was $350 million. For comparison: in 2015 the world spent about $5.3 *trillion* in fossil-fuel subsidies and external costs, according to the International Monetary Fund.

Carbon capture and storage requires special attention. The emissions-reduction goals being promised by many countries assume that these nations will be capturing carbon and storing

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it in the ground. The dirty secret is that a proved system does not exist, not to mention a cost-effective one.

Technology exists to capture carbon dioxide (or any fluid) and pump it into geologic reservoirs: the oil industry already pumps CO_2 underground to help push oil out. But using CO_2 to flush a reservoir is very different than securely locking away that carbon for centuries or millennia. If carbon capture could be made feasible and economic, even at a moderate scale, it could greatly enhance emissions reductions. So we should invest in research—in geology, geophysics, hydrology and engineering—a domain in which our federal government has a long and strong track record. Many other countries have substantial expertise in these disciplines as well.

RECLAIMING THE COMMON GOOD

A HEFTY PRICE on carbon, coupled with major investment in technology, can definitely limit climate change. But both steps require government action. That suggests one other necessary step: we need to stop demonizing government and recognize its crucial role in doing the most important thing that markets do not do, which is prioritizing and sustaining the common good.

For the past 30 years the ideology of the unfettered marketplace has so dominated our discourse that most of us can scarcely imagine an alternative way of organizing our affairs. Individuals who try are dismissed as unrealistic, romantic, polemical or (in America) communists. When environmentalist and writer Bill McKibben suggested that a zero-growth economy could provide good lives for people while greatly reducing demand for the earth's dwindling resources, he was mocked. When Pope Francis released his encyclical on climate change and inequality, in which he urged the world to take on the interdependent challenges of caring for the planet and caring for the poor, one prominent public intellectual all but accused him of being a socialist. Another suggested he was "out of touch."

The pope is very much in touch with one essential fact: markets are effective in distributing goods and services efficiently to those who have the money to pay for them, but the needs of the poor go largely unaddressed, and the external costs remain almost entirely unpaid. Our dominant discourse insists that we can solve these problems by continuing the policies and practices that created them. The pope also noted that blind faith in the marketplace leads people to believe that they are free "as long as they have the supposed freedom to consume." So if the government acts to restrict the marketplace, it is (allegedly) restricting our freedom. But there are many different kinds of freedom, and as philosopher Isaiah Berlin noted many years ago, freedom for wolves can lead to the death of lambs, and surely the right to exist is more fundamental than the right to consume.

To build a better world, we first have to seek it. This requires a different vision, one that embraces priorities other than profit and places care—for creation and for one another—at its center. We have to accept the reality that markets are not motivated by the priority of care. And they are certainly not magical.

RETHINKING THE MAGIC OF THE MARKETPLACE

ECONOMIST NICHOLAS STERN and others have made the same point in more prosaic language. Investment in scientific research, public education and infrastructure is a common good, but our commitments to those activities have been weakened in recent decades. Yet history demonstrates that markets, by themselves, do not remedy market failures. Governments do.

In the aftermath of the cold war, conservatives and liberals agreed that market-based democracies had done a better job than centrally planned ones at providing goods and services, as well as protecting civil liberties and quality of life. But even Adam Smith, the champion of laissez-faire capitalism, noted that markets only function well with appropriate rules and regulations. One might have thought that the global financial crisis of 2008, the worst since the Depression, would have reminded us of the need for a reasonable set of rules. Instead we have continued to insist on the "magic of the marketplace," while decades of deregulated capitalism have led to environmental damage on a scale that threatens the very prosperity it is meant to generate.

We need a new conversation about the appropriate role of government in fostering innovation, remedying market failure and tackling inequality. We have to abandon magical thinking and quasi-religious faith in the marketplace. We must acknowledge that we need governance to foster the technologies needed to meet our energy demands without destroying the natural world.

Government is not *the* solution, but it has to be part of the solution. Although international agreements are useful in encouraging national governments to do the right thing, ultimately nations act on a national level. If the 20th century is any guide, once the government lays the foundations for new technologies, the private sector will step in to do what it does best, which is not to invent them but to sell them.

Above all, we have to reject the canard that addressing climate change threatens our liberty. Timothy Snyder—a foremost expert on the history of European fascism—reminds us that "a common American error is to believe that freedom is the absence of state authority." History shows that although state authority can be abused, its absence does not lead to liberty. On the contrary, its absence may open the door to tyranny and tragedy. Appropriate forms of authority are essential to the guarantee of liberty. As disruptive climate change unfolds, they will also be essential to the guarantee of life and the pursuit of happiness. SA

Naomi Oreskes is a professor of the history of science and an affiliated professor of earth and planetary sciences at Harvard University. She is co-author, with Erik M. Conway, of *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco to Global Warming* (Bloomsbury Press, 2010). She also wrote the introduction to the Melville House Press 2015 edition of the papal *Encyclical on Climate Change and Inequality.*

MORE TO EXPLORE

Deep Economy: The Wealth of Communities and the Durable Future. Bill McKibben. Times Books, 2007.

The Bridge at the Edge of the World: Capitalism, the Environment, and Crossing from Crisis to Sustainability. James Gustave Speth. Yale University Press, 2008.

Encyclical on Climate Change and Inequality: On Care for Our Common Home. Pope Francis. Introduction by Naomi Oreskes. Melville House, 2015.

Why Are We Waiting? The Logic, Urgency, and Promise of Tackling Climate Change. Nicholas Stern. MIT Press, 2015.

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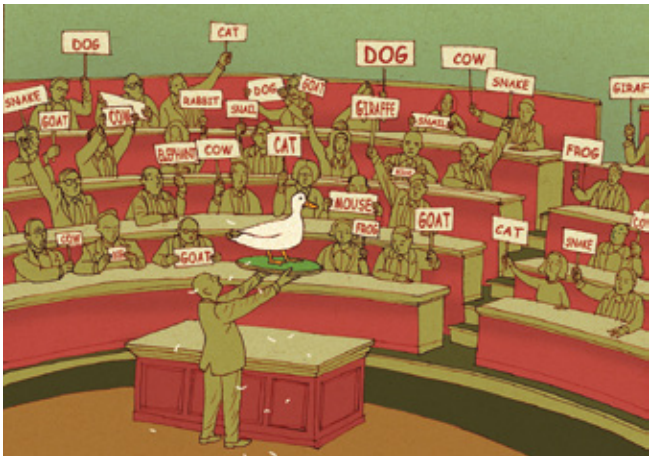
Consilience and Consensus

Or why climate skeptics are wrong

By Michael Shermer

AT SOME POINT in the history of all scientific theories, only a minority of scientists—or even just one—supported them, before evidence accumulated to the point of general acceptance. The Copernican model, germ theory, the vaccination principle, evolutionary theory, plate tectonics and the big bang theory were all once heretical ideas that became consensus science. How did this happen?

An answer may be found in what 19th-century philosopher of science William Whewell called a "consilience of inductions." For a theory to be accepted, Whewell argued, it must be based on more than one induction—or a single generalization drawn from specific facts. It must have multiple inductions that converge on one another, independently but in conjunction. "Accordingly the cases in which inductions from classes of facts altogether different have thus *jumped together,"* he wrote in his 1840 book *The Philosophy of the Inductive Sciences,* "belong only to the best established theories which the history of science contains." Call it a "convergence of evidence."



Consensus science is a phrase often heard in conjunction with anthropogenic global warming (AGW). Is there a consensus on AGW? There is. The tens of thousands of scientists who belong to the American Association for the Advancement of Science, the American Chemical Society, the American Geophysical Union, the American Medical Association, the American Meteorological Society, the American Physical Society, the Geological Society of America, the U.S. National Academy of Sciences and, most notably, the Intergovernmental Panel on Climate Change all concur that AGW is in fact real. Why?

It is not because of the sheer number of scientists. After all, science is not conducted by poll. As Albert Einstein said in response to a 1931 book skeptical of relativity theory entitled *100 Authors against Einstein,* "Why 100? If I were wrong, one would have been enough." The answer is that there is a convergence of evidence from multiple lines of inquiry—pollen, tree rings, ice cores, corals, glacial and polar ice-cap melt, sea-level rise, ecological shifts, carbon dioxide increases, the unprecedented rate of temperature increase—that all converge to a singular conclusion. AGW doubters point to the occasional anomaly in a particular data set, as if one incongruity gainsays all the other lines of evidence. But that is not how consilience science works. For AGW skeptics to overturn the consensus, they would need to find flaws with all the lines of supportive evidence *and* show a consistent convergence of evidence toward a different theory that explains the data. (Creationists have the same problem overturning evolutionary theory.) This they have not done.

A 2013 study published in *Environmental Research Letters* by Australian researchers John Cook, Dana Nuccitelli and their colleagues examined 11,944 climate paper abstracts published between 1991 and 2011. Of those papers that stated a position on AGW, about 97 percent concluded that climate change is real and that it is caused by human activity. What about the remaining 3 percent or so of studies? And what if they are right? In a 2015 paper published in *Theoretical and Applied Climatology,* Rasmus Benestad of the Norwegian Meteorological Institute, Nuccitelli and their colleagues examined the 3 percent and found "a number of methodological flaws and a pattern of common mistakes." That is, instead of the 3 percent of papers converging to a better explanation than that provided by the 97 percent, they failed to converge to anything.

"There is no cohesive, consistent alternative theory to human-caused global warming," Nuccitelli concluded in a commentary published August 25, 2015, in the *Guardian*. "Some blame global warming on the sun, others on orbital cycles of other planets, others on ocean cycles, and so on. There is a 97% expert consensus on a cohesive theory that's overwhelmingly supported by the scientific evidence, but the 2–3% of papers that reject that consensus are all over the map, even contradicting each other. The one thing they seem to have in common is methodological flaws like cherry picking, curve fitting, ignoring inconvenient data, and disregarding known physics." For example, one skeptical paper attributed climate change to lunar or solar cycles, but to make these models work for the 4,000-year period that the authors considered, they had to throw out 6,000 years' worth of earlier data.

Such practices are deceptive and fail to further climate science when exposed by skeptical scrutiny, an integral element to the scientific process. SA

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DOUGLAS SACHA *Getty Images*

vaccines

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Childhood vaccines have transformed medicine. Smallpox has been globally eradicated, polio has been eliminated from the U.S., and diphtheria and congenital rubella have been almost wiped out in North America. Yet some preventable diseases—most notably measles—are managing to make a comeback in certain pockets of the U.S. after a small number of parents have refused to give their children routine immunizations. In the article leading this section, a pediatrician and an epidemiologist detail how intentionally unvaccinated children are helping drive epidemics (*page 48*). And once misinformation takes hold, it can be hard to dispel—especially the thoroughly debunked work linking certain inoculations with autism, as *Scientific American* staff editor Dina Fine Maron writes in the next piece (*page 50*). She takes on the "facts or fiction" about vaccination risks. In the final piece of the section, *Scientific American* staff editor Mark Fischetti illustrates how, although vaccination rates for U.S. children were slipping before 2011, many school immunization laws seem to be having a positive effect (*page 54*). Remaining gaps in vaccination coverage leave community members who are ineligible for vaccines—including adults who have weak immune systems and babies who are too young to get their shots—vulnerable to potentially life-threatening disease.

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Straight Talk about Vaccination

Parents need better information, ideally before a baby is born

By Matthew F. Daley and Jason M. Glanz

WHOOPING COUGH, MEASLES, MUMPS. THESE are the diseases that preyed on our parents' and grandparents' generations and that we thought were fading from existence. In fact, all three diseases have seen a resurgence in the past decade. In 2017 Minnesota suffered a measles outbreak: in a Somali-American community with previously high vaccination rates, concerns about autism led parents to refuse the MMR vaccine against measles, mumps and rubella, and measles spread among the unvaccinated. In 2015 a large multistate measles outbreak started at a California amusement park, and many of those infected were unvaccinated children.

These troubling events show that the failure to vaccinate children endangers both the health of children themselves as well as others who would not be exposed to preventable illness if the community as a whole were better protected. Equally troubling, the number of deliberately unvaccinated children has grown large enough that it may be fueling more severe outbreaks. In a recent survey of more than 1,500 parents, one quarter held the mistaken belief that vaccines can cause autism in healthy children, and more than one in 10 had refused at least one recommended vaccine.

This sad state of affairs exists because parents have been persistently and insidiously misled by information in the press and on the Internet and because the health care system has not effectively communicated the counterarguments, which are powerful. Physicians and other health experts can no longer just assume that parents will readily agree to childhood inoculations and leave any discussion about the potential risks and benefits to the last minute. They need to be more proactive, provide better information and engage parents much earlier than is usually the case.

PERIL OF BUSINESS AS USUAL

RIGHT NOW PEDIATRICIANS typically bring up the need for vaccines during the well-baby checkup held about two months after birth. That visit has a jam-packed agenda. In the usual 20 minutes allotted for the appointment, the physician must learn the answers to many questions, of which the following are but a sample: How many times is the baby waking to feed at night? Is the child feeding well? Where do measurements of height, weight and head circumference fall on a standard growth chart? Do the parents know how and when to introduce solid food and how to safely lay the child down to sleep? Are various reflexes good? Can the sounds of a heart murmur be heard through the stethoscope? Are the hip joints fitting properly in their sockets, or are they dislocated?

Generally in the final seconds of the visit, assuming all has gone well up to this point, the doctor mentions the required schedule for six recommended inoculations: the first DTaP shot (for diphtheria, tetanus and pertussis, also known as whooping cough), the polio shot, a second hepatitis B shot (the first having been given in the first few days after birth), the pneumococcal conjugate shot (for bacterial pneumonia and meningitis), the Hib shot (for another type of meningitis) and finally the oral rotavirus vaccine (to prevent a severe diarrheal infection). This is the point in the visit at which more and more pediatricians report a disheartening turn of events: although most parents agree to the inoculations without hesitation, a growing number say they would like to delay or even refuse some or all of the vaccinations for their infants.

A proper conversation that respects the reluctant parents' concerns, answers their questions and reassures them that the inoculations are indeed necessary—that countless studies by hundreds of researchers over many decades have shown that vaccinations save millions of lives—will likely take at least another 20 minutes. Meanwhile, though, other families sit in the waiting room, itching for their own well-baby checkups to start.

Having this discussion at the two-month well-baby visit is too late. By then, parents may have read about any issues on the Web or chatted with other moms and dads in the park. Discussion with medical professionals should begin long before, usually during, or even prior to, the pregnancy.

FEARS AND FACTS

ALTHOUGH PARENTS GIVE many reasons for not wanting to vaccinate their children, we have noticed at least three recurring themes. Some do not believe their children are at risk for diseases such as polio, measles and tetanus, which are now rarely seen in the U.S. Others do not believe that certain vaccine-preventable diseases, such as chicken pox and measles, are particularly serious. And many worry about the safety of vaccines. The concerns may be about immediate, well-defined side effects such

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as fever or may take the form of anxiety that vaccines might harm the immune system or cause chronic diseases years later. Each of these concerns can be met with a careful review of the evidence.

Together we have conducted a series of studies to better quantify the risks of not vaccinating—information that speaks to the mistaken belief that today's children are unlikely to come down with whooping cough, measles or the like if they skip their inoculations. Our investigations looked at hundreds of thousands of children in Colorado and compared the risk of various vaccine-preventable diseases in children whose parents had refused or delayed vaccines with the risk in children whose parents had had them vaccinated. We found that unvaccinated children were roughly 23 times more likely to develop whooping cough, nine times more likely to be infected with chicken pox, and 6.5 times more likely to be hospitalized with pneumonia or pneumococcal disease than vaccinated children from the same communities.

Clearly, the parental decision to withhold vaccination places youngsters at greatly increased risk for potentially serious infectious diseases. These results also show the flaws in the "free rider" argument, which erroneously suggests that an unvaccinated child can avoid any real or perceived risks of inoculation because enough other children will have been vaccinated to protect the untreated child.

Depending on fate to soften the blow from an infection is also more dangerous than most people realize. One out of every 20 previously healthy children who get the measles will come down with pneumonia. One out of 1,000 will suffer an inflammation of the brain that can lead to convulsions and mental retardation, and one to two out of 1,000 will die. Similarly, chicken pox can lead to severe infections of the skin, swelling of the brain, and pneumonia. Even when no complications arise, chicken pox is painful and triggers high fevers and itchy rashes. Vaccinated children who develop chicken pox (no vaccine is perfectly effective all the time) usually suffer much milder symptoms.

Even when parents appreciate the peril of not vaccinating, they want to know that vaccines are safe. Because vaccines are given to huge numbers of people, including healthy infants, they are held to a much higher safety standard than medications used for people who are already sick. Nothing in medicine is 100 percent safe, however, and the absolute safety of vaccines cannot be proved. Safety can be inferred, though, by the relative absence of serious side effects in multiple studies.

Studying the safety of vaccines is a complicated, labor-intensive process. Fortunately, the U.S. has a sophisticated system, a federally funded program that does not receive any money from vaccine manufacturers. This system can both test specific hypotheses and perform general monitoring of the safety of newly licensed vaccines. As a new theory arises, it can be rigorously tested.

ASSUMPTIVE APPROACH about vaccinations changes parental attitudes about the shots.

Perhaps the biggest boost to the antivaccine movement came in 1998, when, in a paper in the *Lancet,* Andrew J. Wakefield and 12 colleagues proposed that the measles vaccine could cause autism in susceptible children. In the years since, more than a dozen studies have convincingly shown that vaccines do not cause autism. In fact, it is rare in science that published scientific findings have been so thoroughly, and publicly, disproved. The *Lancet* retracted the Wakefield article in early 2010. Most of the co-authors no longer vouch for the study findings. And Wakefield himself was accused of falsifying the data and lost his medical license.

Despite the complete dismantling of Wakefield's vaccines-cause-autism hypothesis, public skepticism about vaccination has only increased as new speculative theories have been put forward. Maybe, some contend, vaccine preservatives cause long-term problems. Or maybe the growing number of vaccines all assaulting the immature immune system at once causes complications. Or perhaps trouble can arise from a toxic combination of vaccines with air pollution, chemical and metal contamination of the environment, and the increasing stress of modern life.

This cycle—debunked links followed by ever grander speculation—keeps repeating itself and is a clear indication that the scientific community is more reactive than proactive when engaging the public about vaccine safety.

So where does this leave the conversation between parents and health professionals? Several promising strategies may be emerging. We recently completed a multiyear randomized controlled trial. We found that an Internet-based intervention delivered during pregnancy and early childhood successfully improved the vaccine attitudes of parents who were already hesitant about vaccination. The intervention also improved vaccination rates. Another group of researchers has found that using a presumptive approach ("Here are the vaccines we'll be giving today") rather than a participatory style ("What do you want to do about vaccines today?") was associated with a higher parental intention to vaccinate. While these strategies need to be explored further, we know that parents also want a nonjudgmental face-to-face conversation with their child's doctor. And many will still want their infant's doctor to look them in the eye and say, "This is one of the best things you can do for your child's health."

The key facts parents need to know, though, are that vaccines prevent potentially fatal diseases, that vaccines have a high degree of safety, and that their safety is constantly evaluated and reevaluated in a system operating independently from the pharmaceutical companies that make vaccines. Unless this message gets spread widely and well, too many doctors and parents are going to find themselves in emergency rooms and isolation wards, watching children suffer with the devastating effects of measles, whooping cough or some other readily preventable infectious disease. SA

Matthew F. Daley is a pediatrician and researcher at Kaiser Permanente's Institute for Health Research in Denver.

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GETTY IMAGES

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FACT OR FICTION?:
VACCINES ARE DANGEROUS

Overwhelming medical evidence shows that negative side effects are rare and minor

By Dina Fine Maron

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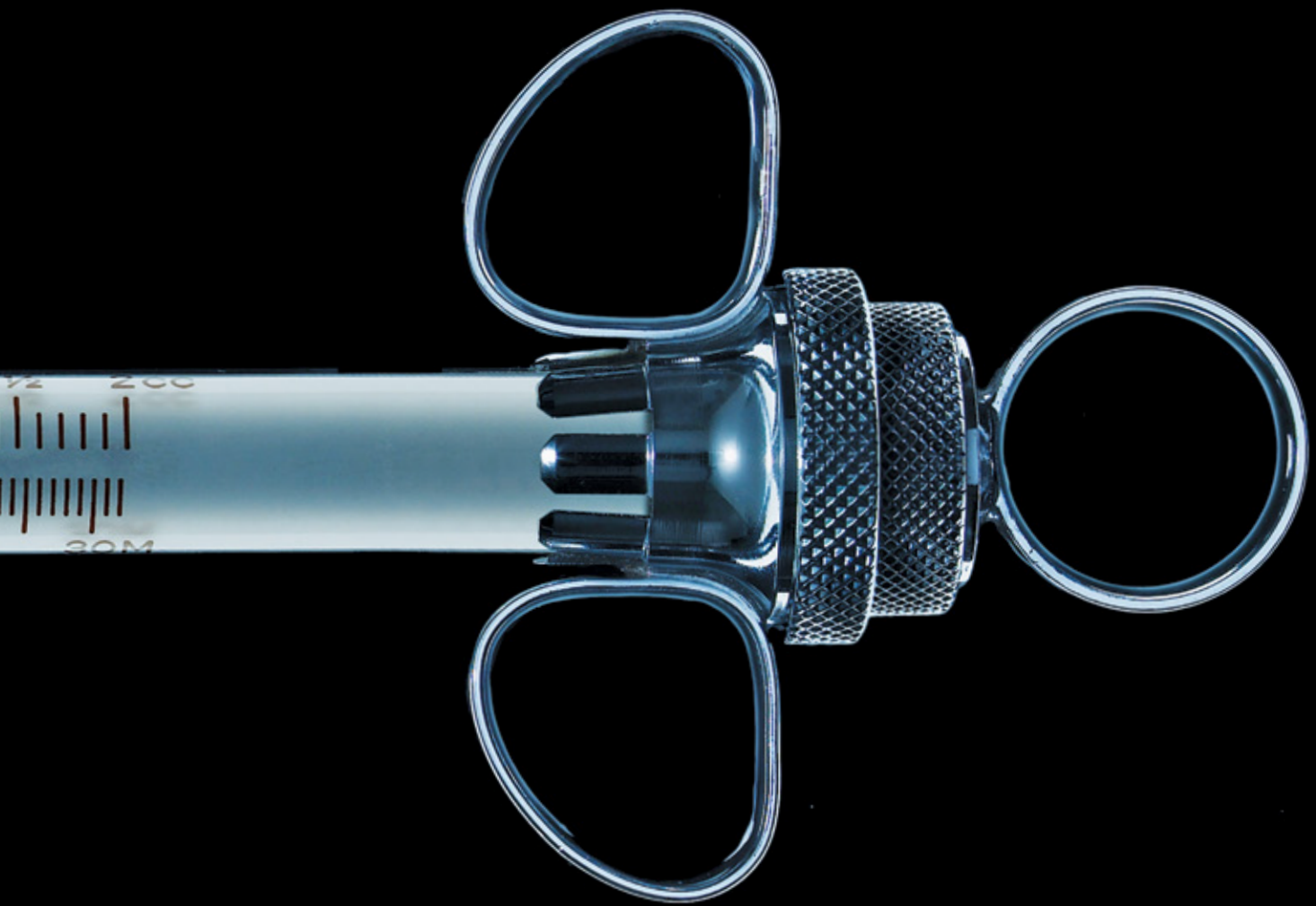

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THE WORLD GREETS NEWBORN BABIES BY BOMBARDING THEM WITH EVERYTHING from dust to disease-causing microbes. Babies can deftly parry exposures to certain harmful substances, thanks to antibodies passed onto them in the womb. But this kind of inherited immunity is short-lived, so a child must develop her own immune system response to combat life-threatening diseases. That's where vaccines come into the picture. By age two, most children will receive almost 30 shots designed to boost a child's natural defenses against disease. Yet at the same time, parents who take their children for those recommended vaccinations might be inundated with Web site and celebrity-espoused rumors making false claims that shots are not necessary or cause autism.

At best, navigating this landscape can be confusing. But when weighing the risks of encountering life-threatening disease against the benefits of receiving a vaccine there's no contest. The vast majority of children do not experience anything worse than short-lived redness or itching at the spot of the injection. So why is there so much misinformation?

One reason is developmental timing. Children receive a bevy of vaccines before age two, roughly overlapping with when children with autism spectrum disorder may noticeably develop symptoms such as the inability to gain new skills. That coincidence has helped the autism-vaccine connection myth persist. And what may have once been passed around by neighborhood gossip is now amplified worldwide by Web sites and social media. But the science simply does not bear out such fears. In August 2011 the Institute of Medicine (IOM) released a report that examined eight childhood vaccines and potential side effects. It found that vaccines are largely safe and that side effects are usually very rare and minor.

SIDE EFFECTS

The overwhelming medical evidence finds that most vaccine side effects among newborns and young children are mild—swelling, redness and a small, hard lump at the site of the injection—and typically pass within a couple of days. A far less common but serious vaccine side effect, occurring in fewer than one in a million cases, is an immediate allergic reaction that can be treated with common medications to ease itching or swelling or, in more serious cases, by administering epinephrine. Rarely, with certain vaccinations there can be other problems. After receiving the first shot of the measles-mumps-rubella (MMR) vaccination, for example, a child has a roughly one in 3,000 chance of developing a fever that leads to a seizure. Such seizures do not lead to any permanent neurological damage. Moreover, they also occur more generally when kids develop high fevers—afflicting up to 5 percent of young children. That does not mean it is not upsetting to see. "It's hard to watch your child seize," says Paul Offit, a pediatrics professor at Children's Hospital of Philadelphia. His own daughter had a seizure after receiving the combo vaccine against diphtheria, tetanus and pertussis but he says it's important to remember that this type of seizure does not cause long-term consequences. And scientific evidence finds that MMR-related seizures are actually less frequent than ones that occur as a direct result of the measles infection itself.

WHAT'S IN A VACCINE?

When a person encounters a pathogen, there is no way to predict whether it will induce a mild or severe form of disease or how the body will react. But vaccines are selected to contain a weakened or dead form of the disease-causing germ that can spark an immune response. Exposure will thus allow the body to build up immunity in a controlled way. The immune system reaction stops this compromised foreign invader in its tracks at the site of injection. And the key to vaccine success is that, afterward, the immune system starts to create fast-response infection fighters called memory cells that will circulate throughout the body and be able to recognize (and fend off) that same pathogen in the future.

These weak or killed stimulants, called antigens, are grown in a lab setting, isolated and then mixed with preservatives, stabilizers and a substance like aluminum that will trigger the immune system to vigorously respond to the vaccine. The process saves lives: among children born in the past two decades, vaccinations will prevent more than 20 million hospitalizations and 732,000 deaths, according to U.S. Centers for Disease Control and Prevention estimates.

WHY DO VACCINES CAUSE ANY SIDE EFFECTS?

Like any medicine, immunizations can lead to a negative reaction. That's not surprising because every individual is different. Genetic variations, immune deficiencies and environmental exposures all contribute to how a person's body reacts to inoculations against disease.

IS SUCH A HIGH NUMBER OF SHOTS DANGEROUS?

Expert medical bodies, including the American Academy of Pediatrics (AAP), urge parents to vaccinate their kids against 16 diseases. The CDC schedule for childhood vaccinations, which relies on recommendations from the Advisory Committee on Immunization Practices and is endorsed by the AAP, is drawn up based on data detailing when the body's immune system will mount the best response to the vaccine and, second, balanced against the need to protect kids at the earliest age possible. There are no scientific data suggesting a medical ben-

PRECEDING PAGES: DWIGHT ESCHLIMAN *Getty Images*

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The Latest Trends in Vaccine Research

Vaccines are vital to safeguarding human health, and research in this wide field progresses rapidly. Recent developments in vaccines have been extensively covered by Dina Fine Maron on ScientificAmerican.com:

What's Next after Creating a Cancer-Prevention Vaccine? Imagine a vaccine that protects against more than half a dozen types of cancer. We have one.

The human papillomavirus (HPV) vaccine was approved for the U.S. market back in June 2006. A decade of research shows it can prevent almost all cervical cancers and protect against cancers of the mouth, throat and anus. Maron interviews one of the researchers who created the vaccine. *September 6, 2017*

Fighting the Opioid Crisis with Vaccines and Better Chemistry Preliminary data for 2016 suggest there were more than 50,000 opioid overdose deaths. The surge is renewing public focus on efforts to develop vaccines that would block the drugs' euphoric effects and therapies that would tamp down the extreme withdrawal symptoms that can leave an addict feeling like they will die unless they get a fix. *August 17, 2017*

The U.S. Takes Its First Shot at Zika Roughly a year after Brazilian doctors and researchers first suspected a link between a spate of alarming birth defects and the Zika virus, a cadre of potential vaccines were ready for testing in humans. The flurry of action—at breakneck speed compared with most vaccine development—shows how a health emergency and a guaranteed global market can prod the process to move a lot faster than usual, with streamlined approvals and millions of dollars in government support. *June 21, 2016*

First Dengue Fever Vaccine Gets Green Light in Three Countries The virus that causes dengue is spread by mosquitoes and infects as many as 400 million people a year worldwide. Severe forms of the painful, flulike disease can be fatal, especially among children. And until late 2015 there was no truly effective prevention except avoiding getting bit. Dengvaxia, developed by the French pharmaceutical company Sanofi, was approved for use in Mexico, the Philippines and Brazil. *December 30, 2015*

Spreading Measles Outbreak Also Takes Heavy Economic Toll Nobody knows what triggered a measles outbreak linked to a Disneyland Park in California in 2015, but officials at the U.S. Centers for Disease Control and Prevention say it was most likely an overseas traveler visiting while infectious. The genetic fingerprints from nine patients in the growing outbreak are all identical to the measles virus that fueled the massive 2014 measles outbreak in the Philippines. The outbreak shows the value in monitoring diseases internationally as well as continuing to vaccinate U.S. citizens. *February 5, 2015*

efit from spacing out vaccines over a longer period than the official recommendations.

Vaccines are also regularly evaluated for safety. Before they are added to the recommended regimen, they must undergo testing to make sure they won't interfere with one another. Multiple studies have also evaluated vaccines' cumulative effects.

Still, pediatricians face continual pressure from some worried parents who may want to spread out the recommended inoculations or postpone certain vaccinations, decisions that can prolong the period of vulnerability to disease. For example, a nationally representative study published in the April 2015 *Pediatrics* found that in an average month 93 percent of surveyed doctors received at least one request from parents to spread out shots. And it happened fairly frequently: over a fifth of the 534 surveyed physicians reported that 10 percent of parents made such requests. Parents' wishes were then often honored—most of the surveyed clinicians ultimately agreed to do so, at least some of the time.

Yet fears about a child's body not being able to handle potent vaccines are misguided. Children's immune systems respond to several hundred foreign substances that trigger an immune response every day. In contrast, the complete schedule of recommended childhood vaccinations includes less than 200 antigens.

DO VACCINES CAUSE AUTISM?

Some concerns about vaccines stem from discredited work that suggested they lead to autism. (The findings were subsequently retracted, and the physician who did that small study was barred from practicing medicine because of ethical lapses.) More than a dozen studies have added to the body of evidence that this link does not exist. Expert groups, including the IOM and the AAP, agree that vaccines do not contribute to children's autism rates. The vaccine additive thimerosal, a preservative that contains a form of mercury (organomercurial, not methylmercury) also does not cause autism. It is now only included in pediatric vaccines in trace amounts (or not at all), but there is no medical evidence that it causes autism in patients.

CAN'T CHILDREN THRIVE WITHOUT VACCINES?

We live in a crowded, fast-moving world, and disease travels easily. The data are clear: failure to immunize a child comes with a much more formidable risk—leaving children vulnerable to contracting a potentially debilitating or lethal illness. Some children are too sick or too young to receive inoculations, so they remain at risk. If those children or other unvaccinated kids come into contact with someone else who was not protected against certain microbes, that can set off a wave of disease such as the measles outbreak in the U.S. in the summer of 2017. Maladies that have become uncommon, such as polio and measles, can also quickly reappear if we stop vaccinating against them, particularly when they are unintentionally imported across geographic borders. The 2015 measles outbreak that rippled through the U.S., for example, had genetic markers that suggest it came from an overseas traveler. Protecting kids actually helps protect everyone. SA

Dina Fine Maron is an award-winning journalist and an editor at *Scientific American* covering medicine and health. She is based in Washington, D.C.

MORE TO EXPLORE

Does This Ebola Vaccine Herald the End of the Virus? Dina Fine Maron. ScientificAmerican.com; August 4, 2015.
What's behind the 2016 Mumps Spike in the U.S.? Dina Fine Maron. ScientificAmerican.com; December 16, 2016.

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Safer by Kindergarten

School immunization laws are working

By Mark Fischetti / Graphic by Jan Willem Tulp

THE NUMBER OF U.S. CHILDREN FULLY vaccinated against potentially deadly diseases such as diphtheria and measles had been slipping before 2011. Since then, national declines have slowed or even reversed. Rates for kindergartners are noticeably higher than for children 19 to 35 months old because of state laws requiring them to have the full series of inoculations before they can enter the classroom. The laws vary, "but overall they say, 'We have to protect our children.' It's terrific," says William Schaffner, professor of preventive medicine at Vanderbilt University. Vigilance remains needed, however; levels have eroded slightly for the older group. That may be because laws in some states do not require the entire series of recommended doses or allow parents to easily obtain exemptions. Young parents may seek to opt out because they do not think diseases are serious and may not have learned about them in middle or high school health classes, which tend to focus on subjects such as sexual activity and drug use. SA

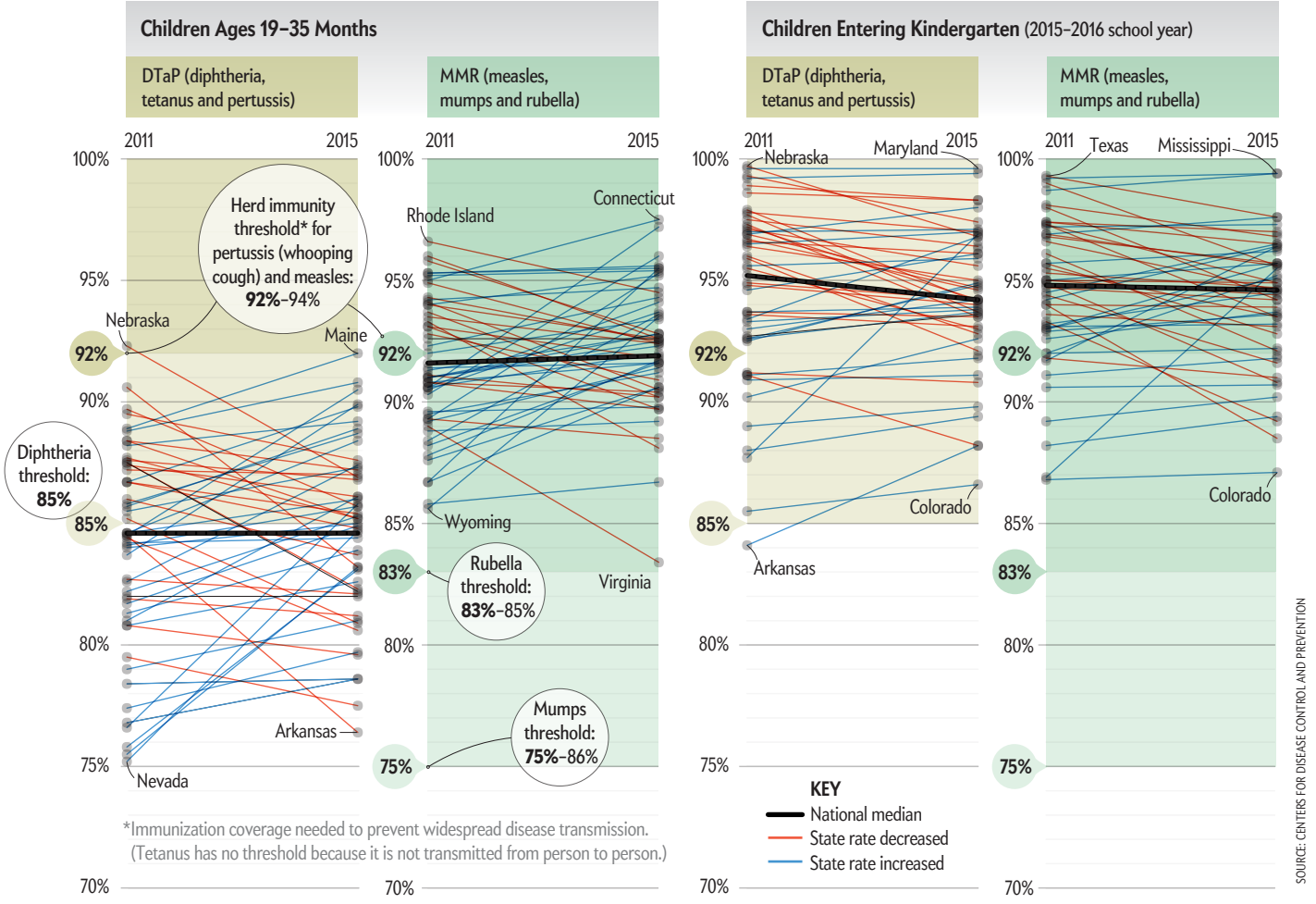
HOW MANY DOSES?

The U.S. Centers for Disease Control and Prevention recommends four doses of DTaP vaccine and one dose of MMR vaccine by the time children are 19 to 35 months old. It recommends five doses of DTaP and two of MMR by ages four to six, which is what most states require for school entry. Data below are for these levels.

NO MORE EXEMPTIONS

Some parents are determined to skirt kindergarten immunization laws, which can pull down a state's average. In 2016, when California ended exemptions based on a parent's religious or philosophical beliefs, medical exemptions—authorized by doctors or forged in their names—tripled, compared with 2015.

Changes in Vaccination Coverage by State, 2011–2015



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guns

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Guns, many people believe, protect us from harm and crime. Moreover, guns themselves are protected: There is a clause in the U.S. Constitution that is often interpreted as a right to bear arms; there is a powerful gun lobby that takes aim at any attempt to restrict firearm use; there are hunters who enjoy having weapons; and there are politicians who fight for more and easier gun ownership. Despite epidemics of shootings, including massacres of schoolchildren, many think the good in guns outweighs the danger. That belief is wrong. The data in an overwhelming number of scientific studies show that more guns actually mean more crime (*pages 56* and *62*). They show guns are rarely used in self-defense, and when they are, the user is often injured (*page 74*). Access to guns also enables impulsive suicide attempts (*page 72*). The ongoing science is providing an ever clearer message: guns do not keep people safe.

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THE GUNFIGHTER

A researcher studies the consequences of the ubiquity of guns in the U.S.

By Meredith Wadman

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WITH HIS CRISP BLUE SUIT AND WIRE-FRAMED spectacles, Garen Wintemute hardly looked frightening as he stepped to the podium on a spring day in 2013 to address a conference on pediatric emergency medicine in San Francisco. But his presence there made the organizers nervous.

Wintemute, an emergency department doctor and longtime director of the Violence Prevention Research Program at the University of California, Davis, today also heads the newly inaugurated University of California Firearm Violence Research Center, launched in July 2017 with a $5-million, five-year commitment of state funding. He is a natural for the role: he has published dozens of papers on the effects

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of guns in the U.S., where widespread gun ownership and loose laws make it easy for criminals and potentially violent people to obtain firearms. Wintemute has pushed the bounds of research, going undercover into gun shows with a hidden camera to document how people often sidestep the law when purchasing weapons. He has also worked with California lawmakers on crafting gun policy and helped to drive a group of gun-making companies out of business.

All this made Wintemute a potentially risky speaker for the organization hosting the 2013 conference, a branch of the U.S. Department of Health and Human Services, which is barred by law from providing funds to any activities that advocate or promote gun control. The meeting organizers had told Wintemute to stick to facts and avoid any mention of policies. But with the nation still reeling from the murder of 20 children and six educators at the Sandy Hook Elementary School in Newtown, Conn., in December 2012, the conference organizers were not sure what Wintemute would say.

He stuck to the facts but also managed to make clear how he feels about the funding prohibition, which had effectively killed off most research on gun violence. "We don't have a labor force," Wintemute told the assembled doctors.

That has led to a striking imbalance in U.S. medical research. Firearms accounted for more than 31,000 deaths in America in 2011. But as Wintemute stepped to the podium in 2013, fewer than 20 academics in the country were studying gun violence, most of them economists, criminologists or sociologists. Wintemute is one of just a few public health experts devoted to this research, which he has funded through a mixture of grants and nearly $2 million of his own money.

His undercover gun-show tactics have led him into situations where he feared for his safety, and they have also raised protests from some gun-rights advocates, who charge that Wintemute is more a biased campaigner than a researcher.

But even a few of his ideological opponents praise Wintemute's work. "Garen is one of the very best in terms of his research skills," says David Kopel, research director at the Independence Institute in Denver, a think tank that supports gun-owners' rights.

And Wintemute, who is 65, makes no apologies for his passion or his methods. "I believe just as strongly as I can articulate in the value of free inquiry," he says, "especially when the stakes are so high—when so many people are dying through no fault of their own; when so much of the country simply turns its back on this problem."

AIMING TRUE

WINTEMUTE GREW UP in a home in Long Beach, Calif., where his father, a decorated veteran of the Second World War, kept a Japanese officer's saber and infantry rifle, a Winchester carbine and a Marlin .22 caliber rifle in a bedroom cupboard. Wintemute learned to shoot and begged to go hunting. That chance came when he was around 12, and his father asked him to help clear out sparrows from the rafters of his company's warehouse.

Wintemute's aim was good, he recalls. "But I held those birds and looked at the finality of it all and felt them turn cold in my hands and decided this was not for me."

As an undergraduate at Yale University, Wintemute flirted with oceanography and neuroscience but eventually decided that he wanted to be a physician. After completing medical school and a residency in family practice, both at U.C. Davis, Wintemute went to work in 1981 as medical coordinator at the Nong Samet Refugee Camp, just inside Cambodia's border with Thailand. The camp was in an area that had only recently been liberated from Khmer Rouge dictator Pol Pot, and Wintemute took care of gunshot wounds on a daily basis. Even more common were shrapnel injuries from land mines. There was no electricity, and amputations were done under local anesthetic.

"I never once met an intact family," Wintemute recalls. "Everybody had lost somebody. There came a point where I said: 'I need to pick up a rifle. I can't be on the sidelines.' "

But instead of grabbing a gun, Wintemute decided to pursue "big picture" international health. He left Cambodia and enrolled in a one-year master's program in public health at Johns Hopkins University. One of his first courses was taught by a former trial lawyer named Stephen Teret, who is now co-director of the Center for Law and the Public's Health at Johns Hopkins.

Teret remembers the day in September 1982 when the students of that class introduced themselves, and Wintemute stunned him with his charisma and eloquence. "I said to myself: 'I'm going to get to know this guy,' " Teret recalls, and the two of them soon became friends and collaborators.

On a cold winter day several months later, some close friends of Teret's dropped their 21-month-old son off at the house of his caregiver. Around noon, the caregiver laid him down for a nap and left the room, whereupon her four-year-old son took his father's loaded handgun from a nearby drawer, pointed it at the sleeping infant and shot him through the head.

Within weeks Teret switched his main research focus from motor vehicle injuries to gun injuries, an area in which public health research was all but nonexistent. Wintemute began assisting him, and their first project was a law review article laying out a legal strategy for suing gunmakers who fail to use available safety technologies to prevent accidental gun deaths.

Wintemute returned to U.C. Davis, with the goal of focusing on gun injuries.

In Cambodia and then in the Sacramento emergency department, Wintemute learned the hard lesson that, as a doctor, he had little chance of saving many people with gunshot wounds; most of those who died did so before they even reached the hos-

IN BRIEF

Physician Garen Wintemute has devoted his career to research on firearms and gun violence, despite government restrictions on funding. He has used upward of $2 million of his own money to further his studies over the past 30 years.

Wintemute has used alternative methods to collect data—attending gun shows with hidden surveillance equipment. These practices have made him a target of progun activitists.

He has published groundbreaking findings on violence and handgun availability. His latest work is evaluating the efficacy of a California policy to confiscate firearms from individuals who have committed violent crimes.

PRECEDING PAGES: CRAIG BERG *Getty Images*

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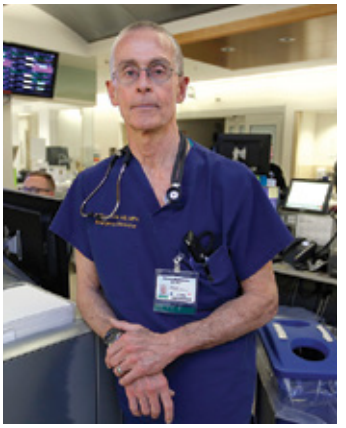
pital. He realized that if he wanted to reduce deaths from firearms, he needed to prevent shootings in the first place.

One day he set himself a question as he left for a run in the foothills east of Sacramento. Looking to make an impact, he wondered, "What subset of firearm injuries can people simply not turn away from?" By the time he got back, he had decided to focus on the kind of shooting that had shattered the lives of Teret's friends.

In June 1987 Wintemute published a paper called "When Children Shoot Children: 88 Unintended Deaths in California." He reported that in 36 percent of these cases, the shooters didn't think that the gun was loaded or was real, or they were too young to tell the difference. Forty percent of the children's fatal injuries were self-inflicted, including separate incidents in which a five-year-old boy and a two-year-old boy, using .38-caliber revolvers—one found under a pillow, the other in his parents' bedroom—each shot himself in the head.



WINTEMUTE IN THE ER, a vigilant firearms reseracher.

RICH PEDRONCELLI *AP Photo*

To illustrate one facet of the problem, Wintemute borrowed several of the guns used in the shootings from the Sacramento medical examiner. He then bought toy lookalikes, mounted the paired guns on a piece of plywood and, when the paper was published, called a press conference. Few of the reporters who attended could tell the toy guns from the real ones. His work and other events that year focused scrutiny on toy guns, and in December toy retailers began to pull realistic-looking toy guns from their shelves. The next year California banned their sale and manufacture.

Wintemute was increasingly convinced that gun manufacturing was a pressure point that could be turned to advantage, by tying the industry to the public health consequences of its products. He was contemplating how to do that when the *Wall Street Journal* published an article about a group of companies in and around Los Angeles, owned by one extended family that made small-caliber, inexpensive handguns known as "Saturday night specials." Poorly made and lacking some safety features, the guns were disproportionately used in crime, particularly by juveniles.

The article contained a trove of details about the family that ran the companies, and Wintemute decided to follow that trail. The result was *Ring of Fire,* a book published in 1994 that described the enterprise and impact of the six companies, which in 1992 produced 34 percent of the handguns made in the country.

Ring of Fire painted such a stark portrait of the problematic guns that "it became the focus of the rallying cry for local legislative action," says Sayre Weaver, a lawyer who represented West Hollywood, the first of several Los Angeles communities to ban the sale of the Saturday night specials. In 1999 the California legislature followed by making it illegal to manufacture and sell the handguns. Within several years, five of the six companies were out of business.

BATTLE TO SURVIVE

ALTHOUGH HIS BOOK had a big impact, Wintemute's research soon hit a snag. With grant support from the U.S. Centers for Disease Control and Prevention, Wintemute had been conducting a retrospective cohort study looking at whether handgun buyers with prior misdemeanor convictions are more likely than those without a criminal history to be charged with new crimes, particularly those involving firearms and violence. (Many states allow purchases by criminals who have been convicted of misdemeanors, such as assault.)

But as he was digging into the study, his source of funding came under attack from the National Rifle Association (NRA), a powerful lobbying group based in Fairfax, Va., that supports gun ownership. NRA leaders were upset with the CDC for funding work by another researcher who had found that people with a gun in their home were 2.7 times more likely than those without one to be murdered and 4.8 times more likely to commit suicide.

In 1996 the NRA persuaded the late Representative Jay Dickey of Arkansas to insert language into a budget bill to prohibit the CDC from advocating or promoting gun control. (That ban has been renewed every year since then.) Dickey's amendment also stripped $2.6 million from the agency's 1997 funding—the exact amount that the CDC had spent on firearm research the previous year.

Also in 1996 Wintemute had received $292,000 from the CDC for the misdemeanor study, but after the change, the agency provided just $50,000 to close down the program.

The research restrictions were extended in 2012 to encompass all of the CDC's parent agency, the Department of Health and Human Services. And they have had a measurable effect. According to an analysis of Elsevier's Scopus database by the group Mayors Against Illegal Guns, the proportion of all publications dealing with U.S. firearms and their impacts declined by 60 percent between 1996 and 2010. On the heels of the Sandy Hook murders, President Barack Obama in 2013 ordered the CDC and other health research agencies to resume firearms violence research, on the grounds that the Dickey amendment prohibits advocacy for gun control but not research on gun violence. In each of the years 2014 through 2017, Obama asked for $10 million for CDC firearms research. Congress did not enact the requests, and the CDC launched no gun-specific research.

In 2013, however, the National Institutes of Health opened a multimillion-dollar grant program supporting researchers to probe the health consequences of violence and how to prevent it. The agency wasn't coy: the program's title included the words "Particularly Firearm Violence." The program lapsed in January 2017, and agency officials have not renewed it, although renewal is "still under consideration," said Renate Myles, an agency spokesperson. She added that "the agency continues to accept research applications about violence, including firearms violence," through general funding mechanisms.

U.S. researchers still produce more papers per capita on the topic than investigators from other countries do. But the subject may not be as high on other countries' research agendas, because gun ownership is so much lower in most developed nations. The U.K., for example, banned private possession of hand-

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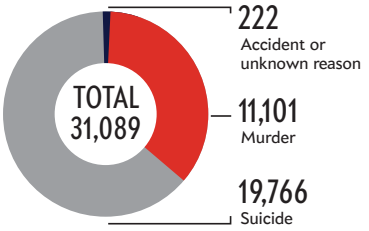
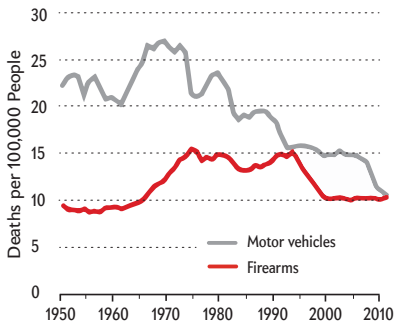
Gun Deaths

Firearms accounted for 1.2 percent of U.S. deaths in 2011, with suicides being the largest fraction.

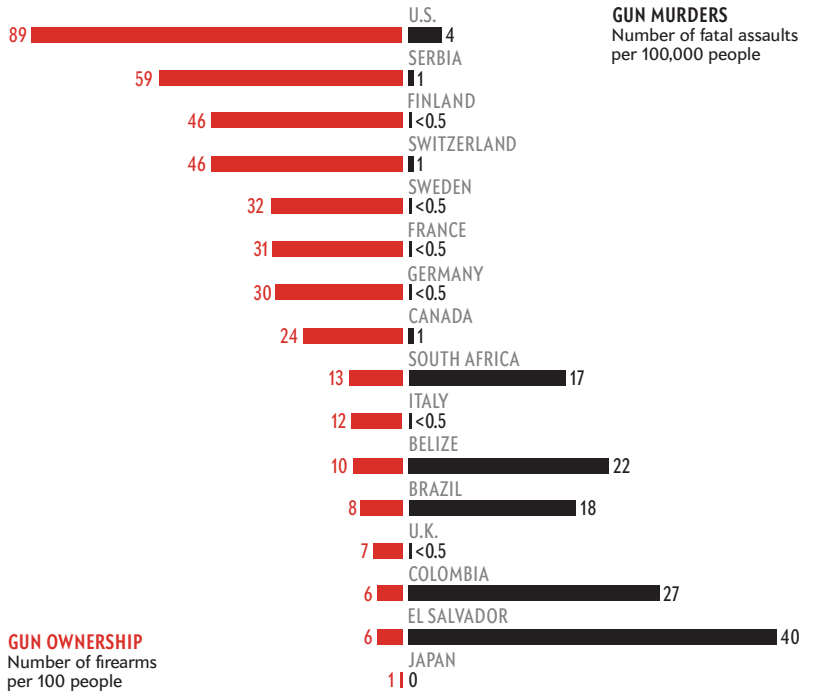


Unlike deaths from car accidents, the rate of gun fatalities has flattened out. Research restrictions have hampered efforts to explain the gun trend.



Top Gun

The U.S. has the most firearms per capita and the greatest number of gun murders of any developed nation.



guns in 1998 after a gunman shot and killed 16 children and their teacher in a school in Dunblane, Scotland.

Wintemute was rare in staying devoted to gun research after the restrictions were imposed. He turned to the California Wellness Foundation, a large private charity based in Los Angeles that focuses on health care and health education, and the foundation provided the funds to complete his study. Wintemute followed up on nearly 6,000 authorized handgun purchasers, most of them for 15 years. He found that men who had had two or more convictions for misdemeanor violence were 15 times as likely as those with no criminal history to be charged with the most violent crimes.

In the years since Wintemute's 2013 conference appearance, his prominence has grown, and his research has expanded, thanks to $848,000 in NIH funding from the now discontinued program and to $2.2 million in support from the National Institute of Justice, the research arm of the U.S. Department of Justice. The California Department of Justice and several private foundations have also funded his work, and U.C. Davis has guaranteed portions of four staff members' salaries for several years. The staff of his Violence Prevention Research Program, then at four, including him, has grown to 15; eight of the new hires have Ph.D.s. And with the California money in hand, Wintemute is gearing up to hire more analysts and support staff. The financial backing marks a big change: back in 2013, Wintemute had donated $945,000 over eight years from his own savings and stock sales to support his program. Now, he says, he continues to donate personal funds "because I can," not because he must.

Most significant in Wintemute's published research since 2013 are data published in January in *Injury Prevention* about the relation between alcohol abuse and future violence among firearms owners. The retrospective study of 4,066 Californians who purchased handguns in 1977 found that buyers with prior alcohol-related convictions, mainly while driving under the influence, were four to five times more likely to be arrested for a violent or firearm-related crime in the next 14 years.

The NIH grant, which was funded in 2015 and 2016, allowed Wintemute to launch a much larger follow-up study, which he expects to complete in 2018, looking at the same question in some 116,000 people who legally purchased handguns in California in 2001, with follow-up through the end of 2013.

INSIDE OUT

AS WINTEMUTE DELVED into gun research in the 1980s, he decided to immerse himself in gun culture. He joined the NRA and the rifle and pistol club in Davis, where he practiced shooting at an indoor range. In 1999 he started to visit gun shows, good opportunities to observe firearm purchases. "Gun shows are sort of like zoos," he says. "You can easily see a wide range of behaviors."

At his first show in Milwaukee, the signs used to advertise guns caught his attention. One licensed retailer displayed a Mossberg Model 500 shotgun with a pistol grip next to a poster that read "Great for Urban Hunting." Another sign, beside a Savage rifle, read: "Great for Getto [sic] Cruisers."

Wintemute says that he was astonished by the blatant promotion of guns as murder weapons. "It was clearly a story that had to be told—bearing witness is part of the job—but I wanted to figure out a way to tell the story quantitatively, scientifically."

It took several years of trial and error at shows before he was

SOURCES: CENTERS FOR DISEASE CONTROL AND PREVENTION (*top*); "RESPONDING TO THE CRISIS OF FIREARM VIOLENCE IN THE UNITED STATES: COMMENT ON FIREARM LEGISLATION AND FIREARM-RELATED FATALITIES IN THE UNITED STATES," BY GAREN J. WINTEMUTE, IN *JAMA INTERNAL MEDICINE*, VOL. 173, NO. 9; MAY 13, 2013 (*bottom*); WWW.GUNPOLICY.ORG, 2016 (*right*)

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confident enough of his methods to begin collecting data. He cut off his waist-length ponytail so he would not stand out in the crowds, bought a small camera and placed it in a bag of Panda licorice with a lens-size hole cut in the side. A pen and notepad would attract too much notice, so he set up his office voicemail so that he could call it from his mobile phone and record long messages. He later added a video camera disguised to look like a button on his shirt.

Several times Wintemute was accused of taking unauthorized photographs, and his phone was temporarily confiscated by security personnel, who examined it and found no pictures. After one such episode, he says, a colleague overheard a group of men planning to attack Wintemute outside the show, but he successfully avoided them.

Altogether he attended 78 gun shows in 19 states, strolling the aisles while apparently deep in a phone conversation. A paper on the findings showed, among other things, that the restrictive policies regulating gun shows in California resulted in fewer illegal "straw" purchases—in which someone buys a gun on behalf of a person legally barred from doing so—than in other states.

That publication, and Wintemute's statements in the media, prompted a backlash from proponents of gun ownership. In June 2007 David Codrea, author of a blog called WarOnGuns, had posted Wintemute's picture online with the note: "WARNING! IF YOU SEE THIS MAN, NOTIFY SECURITY IMMEDIATELY." The post identified Wintemute by name and called him an "anti-gun 'researcher'" who stalked gun shows with hidden cameras and recorders.

But by that point, Wintemute says, he had learned all he could and stopped going to shows.

CRITICAL APPROACH

ON THAT SPRING DAY in 2013, after Wintemute spoke to the emergency room researchers in San Francisco, the NRA posted a critique slamming a study that reported that states with more firearm laws had lower rates of firearm fatalities.

The NRA quoted from an unlikely source to attack the paper: Wintemute, who had published a sharp rebuttal to the paper in the same journal. He had argued that the association between more laws and fewer deaths disappeared when the authors accounted for firearm ownership in a state—meaning that it is impossible to say whether the restrictive gun laws save lives by inhibiting gun ownership or whether laws are simply easier to enact in states in which ownership rates are already low. The latter is a more plausible explanation, he wrote.

One of the paper's authors, Eric Fleegler, an emergency physician at Boston Children's Hospital, responds that, "when you look at firearm-related homicides, even controlling for firearm ownership, firearm-related homicides do decrease in states with more gun laws."

This is not the first time that Wintemute has attacked papers he perceives to be weak, even if they point toward policies he would like to see adopted. And he goes no easier on policies that he views as ineffective, even ones that seek to limit firearm ownership. He has, for instance, repeatedly criticized the assault-weapons ban enacted by Congress in 1994, in part because the ban was easily circumvented. Instead he advocates three steps informed by research: requiring background checks for all U.S. gun sales, forbidding alcohol abusers and those convicted of violent misdemeanors from buying guns, and rewriting current federal restrictions on gun ownership to better capture people who are mentally ill and at risk of violence to themselves or others.

Wintemute's rigor has earned the respect of some ideological opponents, but others say that his work betrays antigun biases by, for instance, selectively citing the literature in a way that minimizes the value of firearms for self-defense.

"We have followed his research for many years. Progun scholars have criticized it for just as long," says John Frazer, who in 2013 was director of the Research and Information Division at the NRA's lobbying arm, the Institute for Legislative Action in Fairfax and today is the organization's secretary and general counsel.

Wintemute's work at gun shows has also triggered complaints. Kopel, the Independence Institute's researcher, says that Wintemute's hidden-camera tactics were "sleazy." "I have a higher opinion of him as a guy who looks at the data and analyzes them in a serious way," Kopel says.

Today, with his gun-show days behind him, Wintemute is focused on such analyses, finishing a randomized trial supported by the National Institute of Justice and California's Department of Justice. It is studying roughly 20,000 people who purchased guns legally in California but have since lost the right to own firearms because they committed a violent crime, were served with a restraining order stemming from domestic violence, or were judged mentally ill and potentially violent. Unlike in other states, authorities in California take guns away from those people. Wintemute is aiming to test the effectiveness of the policy by comparing reoffending rates among those whose guns are seized quickly versus those who keep them for longer.

The money from California is separately enabling new work, beginning with a survey of some 2,000 Californians looking at the prevalence of firearm ownership and of firearm violence and its consequences. "The very cool thing is that the legislature appropriated five years of operating funds up front, so it's possible to make long-term plans and engage in research that will take time to complete," Wintemute says.

It's an unfamiliar feeling. But for however long the new support lasts, Wintemute will continue the work he began 30 years ago. For him, it is part of his mission as a physician to relieve suffering. "Everything that was true of firearm violence in the early 1980s is still true today," he declares. "There is a fundamental injustice in violence. People don't ask for it; it comes to them." SA

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Meredith Wadman, a staff writer for *Science,* has covered medical research politics for 20 years. Her book *The Vaccine Race: Science, Politics and the Human Costs of Defeating Disease* (Viking, 2017) will be out in paperback in February.

MORE TO EXPLORE

When Children Shoot Children: 88 Unintended Deaths in California. G. J. Wintemute et al. in *Journal of the American Medical Association,* Vol. 257, No. 22, pages 3107–3109; June 12, 1987.
Ring of Fire: The Handgun Makers of Southern California. Violence Prevention Research Program, 1994. Available online at www.ucdmc.ucdavis.edu/vprp/pdf/RingofFire1994.pdf
Responding to the Crisis of Firearm Violence in the United States: Comment on "Firearm Legislation and Firearm-Related Fatalities in the United States." Invited Commentary by Garen J. Wintemute, on JAMA Internal Medicine. Posted online May 13, 2013.

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JOURNEY TO GUNLAND

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More firearms do not keep people safe, hard numbers show. Why do so many Americans believe the opposite?

By Melinda Wenner Moyer

Photographs by Ben Rollins

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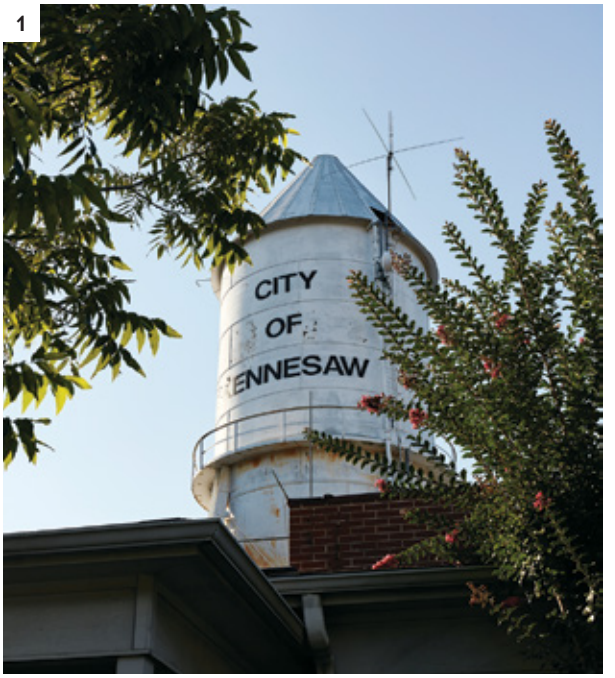
AFTER I PULLED THE TRIGGER AND RECOVERED FROM THE RECOIL, I SLOWLY REFOCUSED MY EYES ON THE TARGET. THERE IT WAS—A TINY BUT DISTINCT CIRCLE NEXT TO THE ZOMBIE'S EYE, THE FIRST BULLET HOLE I'D EVER MADE. I LOOKED DOWN AT THE SHAKING GLOCK 19 IN MY HANDS. A SWIFT AND STRONG EMOTIONAL TRANSFORMATION SWEPT OVER ME. IN SECONDS, I WENT FROM FEELING NERVOUS, EVEN TERRIFIED, TO EXHILARATED AND UNASSAILABLE—AND RIGHT THEN I UNDERSTOOD WHY MILLIONS OF AMERICANS BELIEVE GUNS KEEP THEM SAFE.



GUN CITY: Kennesaw, Ga., near Atlanta, has a law requiring citizens to own firearms (*1*). At the Governors Gun Club outside town, people practice shooting targets (*2*).

I was standing in a shooting range 15 miles south of Kennesaw, Ga., a place known as "America's Gun City" because of a law requiring residents to own firearms. It was day two of a four-day road trip I'd embarked on to investigate a controversial and popular claim made by the gun lobby: that more guns protect more people from crime.

Guns took more than 36,000 U.S. lives in 2015, and this and other alarming statistics have led many to ask whether our nation would be better off with firearms in fewer hands. Yet gun advocates argue exactly the opposite: that murders, crimes and mass shootings happen because there aren't enough guns in enough places. Arming more people will make our country safer and more peaceful, they say, because criminals won't cause trouble if they know they are surrounded by gun-toting good guys.

After all, since 1991 Americans have acquired 170 million new guns while murder rates have plummeted, according to the National Rifle Association of America (NRA). Donald Trump, when running for president, said of the 2015 shooting massacre in San Bernardino, Calif., that "if we had guns in California on the other side, where the bullets went in the different direction, you wouldn't have 14 or 15 people dead right now." Mike Watkins, a cop–turned–firearm instructor at the Kennesaw range, put it this way: "If I'm a bad guy, and I know this place has guns, it's not a place I'm obviously going to want to go and do something bad."

Is there truth to this claim? An ideal experiment would be an interventional study in which scientists would track what happened for several years after guns were given to gun-free communities and everything else was kept the same. But alas, there are no gun-free U.S. communities, and the ethics of doing such a study are dubious. So instead scientists compare what happens to gun-toting people, in gun-dense regions, with what happens to people and places with few firearms. They also study whether crime victims are more or less likely to own guns than others, and they track what transpires when laws make

IN BRIEF

The claim that gun ownership stops crime is common in the U.S., and that belief drives laws that make it easy to own and keep firearms.

But about 30 careful studies show more guns are linked to more crimes: murders, rapes, and others. Far less research shows that guns help.

Interviews with people in heavily gun-owning towns show they are not as wedded to the crime defense idea as the gun lobby claims.

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2

it easier for people to carry guns or use them for self-defense.

Most of this research—and there have been several dozen peer-reviewed studies—punctures the idea that guns stop violence. In a 2015 study using data from the FBI and the Centers for Disease Control and Prevention, for example, researchers at Boston Children's Hospital and Harvard University reported that firearm assaults were 6.8 times more common in the states with the most guns versus those with the least. Also in 2015 a combined analysis of 15 different studies found that people who had access to firearms at home were nearly twice as likely to be murdered as people who did not.

This evidence has been slow to accumulate because of restrictions placed by Congress on one of the country's biggest injury research funders, the CDC. Since the mid-1990s the agency has been effectively blocked from supporting gun violence research. And the NRA and many gun owners have emphasized a small handful of studies that point the other way.

I grew up in Georgia, so I decided to travel around that state and in Alabama, where the belief that guns save good people is sewn into the fabric of everyday life. I wanted to get a read on the science and listen to people with relevant experience: cops, elected officials, gun owners, injury researchers and firearm experts such as Watkins, who stood by my side as I pulled the Glock's trigger.

FOR CLUES ON HOW GUNS AFFECT VIOLENCE, Kennesaw is an obvious place to start. On March 15, 1982, this city 24 miles north of Atlanta passed a controversial law: to "provide for and protect the safety, security and general welfare of the city and its inhabitants," Kennesaw would require that every head of a household own a firearm and ammunition.

Nearly 35 years to the day after the law passed, I drove down Cherokee Street in Kennesaw until I reached the Bobby Grant Center police annex, a small brick building perched in front of a large water tower. The annex houses the city's detectives; the main police department is a quarter of a mile down the street. I picked up the entry phone next to the locked door and buzzed. One second later a big man with a moustache and goatee, who was clearly waiting for me, let me in. He introduced himself as Lieutenant Craig Graydon, the man I was there to meet.

Graydon heads up Kennesaw's Criminal Investigations Division and keeps track of all the city's crime statistics. He led me back to his dark office, where a computer glowed with a screen saver of the cast of the old *Untouchables* TV show, starring Robert Stack as federal agent Eliot Ness. Graydon's great-grandfather and father were both in law enforcement. "I've been around weapons of all kinds for as long as I can remember," he said.

Kennesaw is proud of its gun law. "Inmates have been picked up on other charges around the area, and they've said, 'No, I would never break in a house in Kennesaw,' " Graydon said. City officials tout that a year after the law was implemented, burglaries in Kennesaw dropped by more than half; by 1985 they were down by 80 percent. "It was a selling point for the town," according to David McDowall, a criminologist at the University

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at Albany, S.U.N.Y. The lavish media attention that the law received probably helps: it's not just that Kennesaw residents have guns; it's that everyone *knows* Kennesaw residents have guns. (That said, the rule has never been enforced, and Graydon estimates that only about half of Kennesaw's residents actually own firearms.)

But while burglary numbers did drastically decline in Kennesaw after 1981, those statistics can be misleading. McDowall took a closer look at the numbers and noticed that 1981 was an anomaly—there were 75 percent more burglaries that year than there were, on average, in the previous five years. It is no surprise that the subsequent years looked great by comparison. McDowall studied before-and-after burglary numbers using 1978, 1979 or 1980 as starting points instead of 1981 and, as he reported in a 1989 paper, the purported crime drop disappeared. Kennesaw has always had pretty minimal crime, which may have more to do with the residents and location than how many guns it has.

Yet the sense I got in Kennesaw—which feels like a typical small city, not some gun-frenzied town—is that data don't matter to a lot of people. It was similar in other places I visited. What matters more is apparent logic: guns stop criminals, so they keep people safer. The night before I met Graydon, I attended a lecture by a Second Amendment lawyer in Stone Mountain, Ga., 30 miles southeast of Kennesaw. At one point, the lawyer mentioned Samuel Colt, who popularized the revolver in the mid-19th century. "I haven't seen the statistics, but I've got to assume that the instances of rape and strong-arm robberies plummeted when those became widespread," he said. Numbers and statistics, in other words, were almost unnecessary—everyone just *knows* that where there are more guns, there is less crime.

So what does the research say? By far the most famous series of studies on this issue was conducted in the late 1980s and 1990s by Arthur Kellermann, now dean of the F. Edward Hébert School of Medicine at the Uniformed Services University of the Health Sciences, and his colleagues. In one, published in 1993 in the *New England Journal of Medicine* and funded by the CDC, he and his colleagues identified 444 people who had been killed between 1987 and 1992 at home in three U.S. regions—Shelby County, Tennessee, King County, Washington State, and Cuyahoga County, Ohio—and then collected details about them and their deaths from local police, medical examiners and people who had been close to the victims. They found that a gun in the home was associated with a nearly threefold increase in the odds that someone would be killed at home by a family member or intimate acquaintance.

These findings directly contradict the rationale I kept hearing in Georgia, and that could be because human behavior is a lot messier than simple logic predicts. Researchers posit that even if keeping a gun at home does thwart the odd break-in, it may also change the gun owner's behavior in ways that put that person and his or her family more at risk. "The fact that you have a gun may mean that you do things you shouldn't be doing: you take chances you shouldn't otherwise take; you go to places where it's really not safe, but you feel safe," says David Hemenway, director of the Harvard Injury Control Research Center. This added risk may overpower any protective effects.

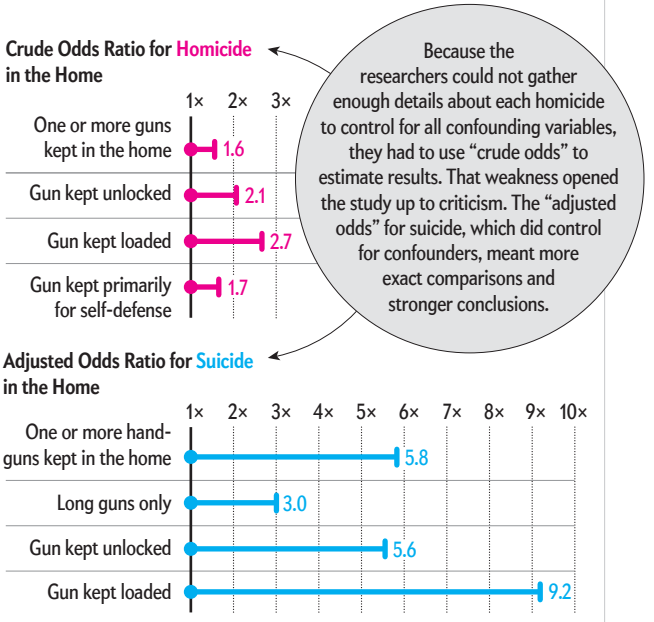
There's also the fact that where there are more guns, more opportunities exist for people to steal them and use them nefar-

An Armed Home Is Not a Safer Home

A common belief is that guns in the house protect those who live there from crime. Not so, according to several studies dating back to the 1980s and 1990s that are supported by more recent work. Guns in the home have been repeatedly linked to an increased risk for homicide and suicide.

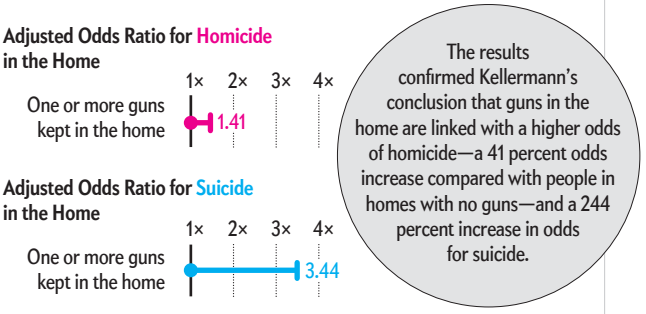
High-Impact Studies

In the late 1980s and early 1990s, Arthur Kellermann, now at the Uniformed Services University of the Health Sciences, and his colleagues published a number of studies suggesting that murder and suicide were more common among people who kept guns in their homes. The risks were indicated by "odds ratios": ratios greater than 1 meant more people with guns in their homes would be victims than would people in gun-free homes. The figures they reported reflected increased odds. For instance, in homes that owned guns for self-defense, the odds ratio of 1.7 referred to a 70 percent increased odds of being murdered at home.


Crude Odds Ratio for Homicide in the Home
1× 2× 3×
One or more guns kept in the home
1.6
Gun kept unlocked
2.1
Gun kept loaded
2.7
Gun kept primarily for self-defense
1.7
Because the researchers could not gather enough details about each homicide to control for all confounding variables, they had to use "crude odds" to estimate results. That weakness opened the study up to criticism. The "adjusted odds" for suicide, which did control for confounders, meant more exact comparisons and stronger conclusions.
Adjusted Odds Ratio for Suicide in the Home
1× 2× 3× 4× 5× 6× 7× 8× 9× 10×
One or more handguns kept in the home
5.8
Long guns only
3.0
Gun kept unlocked
5.6
Gun kept loaded
9.2

Supporting Work

In 2003 Douglas Wiebe, now at the University of Pennsylvania, and his colleagues conducted a similar study comparing gun ownership levels among 3,679 murder and suicide victims and 21,619 similar nonvictims. The researchers were able to gather more information about each subject, allowing them to adjust their odds ratios to account for variables with precision.


Adjusted Odds Ratio for Homicide in the Home
1× 2× 3× 4×
One or more guns kept in the home
1.41
Adjusted Odds Ratio for Suicide in the Home
1× 2× 3× 4×
One or more guns kept in the home
3.44
The results confirmed Kellermann's conclusion that guns in the home are linked with a higher odds of homicide—a 41 percent odds increase compared with people in homes with no guns—and a 244 percent increase in odds for suicide.

Graphics by Jen Christiansen

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BELIEF VS. NUMBERS: Craig Graydon of the Kennesaw police says criminals may be afraid to break into houses in his city, but an analysis of crime rates does not link a decrease to the firearms law.

iously. Indeed, one of Kennesaw's crime problems, Graydon told me, is gun theft, so the Kennesaw Police Department encourages residents to lock their guns up. The NRA, on the other hand, opposes legislation that requires secure gun storage.

The initial work by Kellermann and his colleagues was criticized for not using enough statistical controls. So they went on to publish other studies confirming the link between guns and more violence. In one, they found that a gun in the home was tied to a nearly fivefold increase in the odds of suicide. (More Americans die from gun suicides every year than gun homicides.) In another, published in 1998, they reported that guns at home were four times more likely to cause an accidental shooting, seven times more likely to be used in assault or homicide, and 11 times more likely to be used in a suicide than they were to be used for self-defense.

The research made headlines in the *New York Times* and the *Washington Post*. It also infuriated the gun lobby, which launched a war against gun research that persists today.

ONE VETERAN OF THAT WAR is injury researcher Mark Rosenberg. I drove to Rosenberg's Atlanta-area home—only 15 miles from where I lived as a child—after leaving the Kennesaw Police Department, and we sat down in his living room. In the late 1990s Rosenberg was the director of the CDC's National Center for Injury Prevention and Control, which then funded and studied gun violence. He said he was fired from the agency in 1999 for pushing ahead with this research despite political opposition, although his boss at the time, whom I contacted, disagreed that Rosenberg's actions on gun research caused his dismissal.

I asked Rosenberg what happened after the Kellermann studies came out. "The NRA started a multipronged attack on us," he recounted. "They called the CDC a cesspool of junk science." Indeed, soon after Kellermann's early studies were published, the NRA ran an article in its official journal, the *American Rifleman,* encouraging readers to protest the CDC's use of tax dollars to "conduct anti-gun pseudo-scientific studies disguised as research." The association also asked the National Institute of Health's Office of Scientific Integrity to investigate Kellermann and his colleagues, but it declined. Todd Adkins, current director of research and information at the NRA's Institute for Legislative Action, told me via e-mail that the association was reacting because CDC scientists had started a campaign to persuade Americans that firearms are a menace to public health and ignored data that did not support this idea.

As the dispute continued, Representative Jay Dickey of Arkansas introduced a rider into the CDC's 1996 spending bill mandating that none of its funding be used to advocate or promote gun control. Congress also cut out $2.6 million of the CDC's budget, the exact amount that had been allocated for firearm research the previous year. (Later, that funding was restored but was earmarked for traumatic brain injury.) Harvard's Hemenway says that the move "was a shot across the bow: 'We're watching you.'" He adds that "the CDC recognized that they better be really, really, really, really careful about guns if they wanted to have an Injury Center."

Dickey's addition to the CDC's funding bill has been renewed every year since. In fact, in 2011 the language was extended to cover all Department of Health and Human Services agencies, including the NIH. But Dickey later said that he did not intend to put a stop to all gun research—and he wished that he hadn't. He died this past April.

The CDC's hands are still tied. After the 2012 school shooting that took the lives of 20 children and six adults in Newtown, Conn., President Barack Obama signed an executive order requesting that the CDC spend $10 million on gun violence research. But Congress did not appropriate the funds. In fact, according to Linda DeGutis, who directed the CDC's Injury Center from 2010 to 2014, agency employees weren't even allowed to discuss Newtown. "We couldn't talk to the media except on background. We couldn't be quoted on anything," she recalls. "There were CDC staff members who wouldn't even mention the word 'gun.'" (Current staffers declined to be interviewed for this article.)

Garen Wintemute, a physician and noted gun violence researcher at the University of California, Davis, is not terribly surprised that everything went down the way it did. "It's like doing work in any other controversial field that threatens established interests. Those interests respond in a way to minimize the threat," he says. Rosenberg, after leaving the CDC, became CEO of a nonprofit that works to improve health in developing countries (he retired from that role last year). But Wintemute and others have continued with gun research, procuring grants from private foundations and government agencies such as the

SOURCES: "GUN OWNERSHIP AS A RISK FACTOR FOR HOMICIDE IN THE HOME," BY ARTHUR L. KELLERMANN ET AL., IN *NEW ENGLAND JOURNAL OF MEDICINE*, VOL. 329, NO. 15; OCTOBER 7, 1993; "SUICIDE IN THE HOME IN RELATION TO GUN OWNERSHIP," BY ARTHUR L. KELLERMANN ET AL., IN *NEW ENGLAND JOURNAL OF MEDICINE*, VOL. 327, NO. 7; AUGUST 13, 1992; "HOMICIDE AND SUICIDE RISKS ASSOCIATED WITH FIREARMS IN THE HOME: A NATIONAL CASE-CONTROL STUDY," BY DOUGLAS J. WIEBE, IN *ANNALS OF EMERGENCY MEDICINE*, VOL. 41, NO. 6; JUNE 2003

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National Institute of Justice. In 2005 Wintemute started using his own private money to fund his research and has spent about $1.7 million so far.

More than 30 peer-reviewed studies, focusing on individuals as well as populations, have been published that confirm what Kellermann's studies suggested: that guns are associated with an increased risk for violence and homicide. "There is really uniform data to support the statement that access to firearms is associated with an increased risk of firearm-related death and injury," Wintemute concludes. Gun advocates argue the causes are reversed: surges in violent crime lead people to buy guns, and weapons do not create the surge. But if that were true, gun purchases would increase in tandem with all kinds of violence. In reality, they do not.

When I asked people I met on my trip to Georgia for their thoughts on how guns influence violence, many said they couldn't believe that guns were a root cause. "It's easier to go after the object than it is to go after the motive," Graydon told me. He does have a point: A growing body of research suggests that violence is a contagious behavior that exists independent of weapon or means. In this framework, guns are accessories to infectious violence rather than fountainheads. But this does not mean guns don't matter. Guns intensify violent encounters, upping the stakes and worsening the outcomes—which explains why there are more deaths and life-threatening injuries where firearms are common. Violence may be primarily triggered by other violence, but these deadly weapons make all this violence worse.

MY NEXT STOP, SCOTTSBORO, ALABAMA, is within a county where nearly one in every five people has a permit to carry a concealed weapon. Overall in Alabama, an estimated 12 percent of residents have permission to carry concealed firearms, possibly the highest such rate in the country. Jackson County, home to Scottsboro, ranks close to the top of the state with that nearly one-in-five figure. I wanted to know if people in this sleepy town just north of the Tennessee River commonly used these hidden guns to thwart crime.

I left Rosenberg's home and drove 120 miles northwest. I drove past an Econo Lodge, a No. 1 China Buffet and a CashMart and then parked at the Jackson County courthouse, an impressive Neoclassical brick building with a clock tower. Scottsboro gained notoriety in 1931, when eight black youths were sentenced to death in its courthouse by an all-white jury after being falsely accused of raping two white women, a decision that was appealed up to the U.S. Supreme Court. After passing through the metal detectors, I meandered around in search of the sheriff's office, which I eventually found at the back of the ground floor. A receptionist walked me in to meet Sheriff Chuck Phillips, who was sitting at his desk with his chief deputy, Rocky Harnen. A sheet entitled "Handgun Fundamentals" hung on the wall behind the desk.

"I promise you, everybody here that wants a gun has got one or 100," Phillips told me, drawling out the number so it sounded like "hunnerd." I asked how many times Scottsboro residents had used their guns to protect themselves. "I've been doing this for 35 years, and I just can't recall one," the sheriff answered. Harnen, though, suddenly remembered something. "We did have a lady that was in one of our firearms classes. She had a guy try to break into her house," he recalled. "She yelled and said, 'I've got a gun,' and she opened the door, and he was running away—she fired at him."

CRIME STOPPERS? Mike Watkins, a firearms instructor in Georgia, argues that "if I'm a bad guy, and I know that this place has guns, it's not a place I'm obviously going to want to go."

But they could not think of any other examples. Graydon, back in Kennesaw, also could not remember a time when a resident used a gun in self-defense, and he has been working for the police department for 31 years.

The frequency of self-defense gun use rests at the heart of the controversy over how guns affect our country. Progun enthusiasts argue that it happens all the time. In 1995 Gary Kleck, a criminologist at Florida State University, and his colleague Marc Gertz published a study that elicited what has become one of the gun lobby's favorite numbers. They randomly surveyed 5,000 Americans and asked if they, or another member of the household, had used a gun for self-protection in the past year. A little more than 1 percent of the participants answered yes, and when Kleck and Gertz extrapolated their results, they concluded that Americans use guns for self-defense as many as 2.5 million times a year.

This estimate is, however, vastly higher than numbers from government surveys, such as the National Crime Victimization Survey (NCVS), which is conducted in tens of thousands of households. It suggests that victims use guns for self-defense only 65,000 times a year. In 2015 Hemenway and his colleagues studied five years' worth of NCVS data and concluded that guns are

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The Rarity of Self-Defense

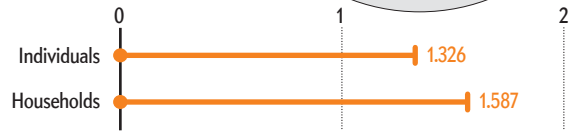
Claims that people frequently need guns to defend themselves from criminals usually rely on one 1995 survey. That survey concluded that Americans used guns to ward off crime up to 2.5 million times in a year. But subsequent research, involving much larger samples, has come up with much smaller numbers, indicating that defensive gun use is unusual.

High-Impact Study

The 1995 work, published by Gary Kleck of Florida State University and his colleague Marc Gertz, randomly asked 5,000 Americans if they, or another member of the household, had used a gun for self-protection in the past year. Just over 1 percent said yes, and the researchers extrapolated this percentage to the entire U.S. population, giving them up to 2.5 million annual instances of defensive gun use.

The figures in this survey are much higher than in other research. The National Crime Victimization Survey, which questions tens of thousands of households, suggests that annually Americans use guns 65,000 times in self-defense. The NCVS questions first establish that people are actual attack victims, whereas the Kleck questions do not. Some worry that Kleck's findings include spurious reports of self-defense use by people who were not actually victimized.

Percent Surveyed Who Said They Had Used a Gun in Self-Defense in the Previous Year



Contradictory Work

In 2015 researcher David Hemenway of Harvard University and his colleagues combed through NCVS data and found there were far fewer uses than Kleck and Gertz reported. The 2015 research involved about 14,000 people who were confirmed victims of crime, unlike the Kleck work. The conclusions indicate gun use for self-defense is quite rare.

This percentage is telling because not only is it lower than the Kleck data, but it also comes from people who were in real crime situations, not a random sample of the general population. Other data from this study indicate that strategies such as calling for help were about as effective as gun use at preventing injury.

Crime Victims Who Used a Gun in Self-Defense during the Incident (percent, 2007–2011)

In 1998 Arthur Kellermann analyzed 626 shootings that occurred around homes in three cities. He found that accidental shootings, homicides, assaults and suicides were much more common than gun use for self-defense:

"Every time a gun in the home was used in a self-defense or legally justifiable shooting, there were four unintentional shootings, seven criminal assaults or homicides, and 11 attempted or completed suicides."

SOURCES: "ARMED RESISTANCE TO CRIME: THE PREVALENCE AND NATURE OF SELF-DEFENSE WITH A GUN," BY GARY KLECK AND MARC GERTZ, IN *JOURNAL OF CRIMINAL LAW AND CRIMINOLOGY*, VOL. 86, NO. 1; FALL 1995; "THE EPIDEMIOLOGY OF SELF-DEFENSE GUN USE: EVIDENCE FROM THE NATIONAL CRIME VICTIMIZATION SURVEYS 2007-2011," BY DAVID HEMENWAY AND SARA J. SOLNICK, IN *PREVENTIVE MEDICINE*, VOL. 79; OCTOBER 2015; "INJURIES AND DEATHS DUE TO FIREARMS IN THE HOME," BY ARTHUR L. KELLERMANN ET AL., IN *JOURNAL OF TRAUMA: INJURY, INFECTION, AND CRITICAL CARE*, VOL. 45, NO. 2; AUGUST 1998

HOME ON THE RANGE near Kennesaw. In a recent survey of American gun owners, 88 percent said they bought handguns for self-defense, and many thought they could be targets of violent crime.

used for self-defense in less than 1 percent of all crimes that occur in the presence of a victim. They also found that self-defense gun use is about as effective as other defensive maneuvers, such as calling for help. "It's not as if you look at the data, and it says people who defend themselves with a gun are much less likely to be injured," says Philip Cook, an economist at Duke University, who has been studying guns since the 1970s.

Kleck and Getz's survey and the NCVS differ in important ways that could help explain the discrepancy between them. The NCVS first establishes that someone has been the victim of an attack before asking about self-defense gun use, which weeds out yes answers from people who might, say, wave their gun around during a bar fight and call it self-defense. Kleck and Getz's survey could overestimate self-defense use by including such ambiguous uses. Kleck counters that the NCVS might underestimate self-defense because people who do not trust government surveyors will be afraid to admit that they used their gun. Yet people who participate in the NCVS are told at the start that they are protected under federal law and that their responses will remain anonymous.

A closer look at the who, what, where and why of gun violence also sheds some light on the self-defense claim. Most Americans with concealed carry permits are white men living in rural areas, yet it is young black men in urban areas who disproportionately encounter violence. Violent crimes are also geographically concentrated: Between 1980 and 2008, half of all of Boston's gun violence occurred on only 3 percent of the city's streets and intersections. And in Seattle, over a 14-year-period, every single juvenile crime incident took place on less than 5 percent of street segments. In other words, most people carrying guns have only a small chance of encountering situations in which they could use them for self-defense.

YET THESE NUMBERS don't resonate with many gun owners. "Absolutely, owning a firearm makes you safer," Phillips told me. Watkins opined that "by having a gun, it gives you the opportunity to refuse to be a victim." (Watkins, who used to be a cop in upstate New York, did later concede that guns are rarely shot in self-defense, even by law enforcement.) In a June 2017 study,

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researchers surveyed American gun owners about why they owned handguns, reporting that 88 percent bought them for self-defense; many felt they were likely to become targets of violent crime at some point. This belief is so pervasive that companies have even started selling self-defense insurance. At the lecture I attended in Stone Mountain, a representative of Texas Law Shield, a firearms legal defense program, tried to get me to sign up for a service that would provide free legal representation in the event that I ever shot someone to protect myself. "You don't need it till you need it, but when you need it, you daggone sure glad you got it," he said.

But even as the belief that we are all future crime targets has taken hold, violent crime rates have actually dropped in the U.S. in recent decades. According to the FBI, rates were a whopping 41 percent lower in 2015 than they were in 1996. The NRA attributes this decrease to the acquisition of more guns. But that is misleading. What has increased is the number of people who own multiple guns—the actual number of people and households who own them has substantially dropped.

Recently researchers have tried to assess the value of self-defense gun use by studying "stand your ground" laws, which gained notoriety after teenager Trayvon Martin was killed by George Zimmerman in Florida in 2012. These laws allow people to kill in self-defense when they feel they are in danger. Progun groups argue that they should deter crime because criminals will know that victims have no reason not to fight back. But a January 2017 study reported that when "stand your ground" was passed in Florida, the monthly homicide rate went up by nearly a quarter. And a 2012 study found that states that adopted these laws experienced an abrupt and sustained 8 percent increase in homicides relative to other states. Mark Hoekstra, a co-author of the 2012 paper and an economist at Texas A&M University, put it this way: "We found that making it easier to kill people resulted in more dead people."

But some argue that even an unused gun can thwart crime. The logic here is that in areas with high rates of concealed carrying, criminals don't want to victimize people who might have guns, so they don't commit violent crimes. The most famous study, published in 1997 by John R. Lott, Jr., then a research fellow at the University of Chicago, and David B. Mustard, an economist now at the University of Georgia, looked at county crime rates in several states that had passed laws making it easy to get gun permits at various times prior to 1992. They compared such rates to crime levels in places that did not have easy access to guns during that period. Their hypothesis: when areas make it easier for people to get permits, more people will get guns and start carrying—and then violence will drop. Lott and Mustard developed a model, based on this comparison, that indicated that when it was easier to get permits, assaults fell by 5 percent, rapes by 7 percent and murders by 7.65 percent. Lott went on to publish a book in 1998 called *More Guns, Less Crime,* which tracked concealed carry laws and crime in more than 3,000 counties and reported similar findings.

Many other researchers have come to opposite conclusions. John Donohue, an economist at Stanford University, reported in a working paper in June 2017 that when states ease permit requirements, most violent crime rates increase and keep getting worse. A decade after laws relax, violent crime rates are 13 to 15 percent higher than they were before. And in 2004 the National Research

Gun Access Does Not Reduce Crime

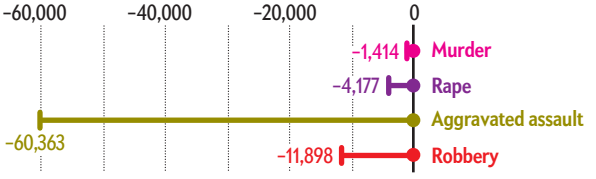
Gun advocates have argued that allowing more citizens to carry more guns—streamlining concealed carry permits—will deter crime. The idea rests largely on a controversial 1997 study that analyzed crime rates and concluded that criminal activity dropped when areas eased permit rules. But the study has been widely criticized and contradicted by other research.

High-Impact Study

The 1997 work by John R. Lott, Jr., now at the Crime Prevention Research Center, and David B. Mustard analyzed U.S. county crime data between 1977 and 1992. It found that murder rates dropped by 7.65 percent in 10 states after they made it easier to carry concealed weapons. The research calculated other crime rates decreased as well.

These figures are projections of the number of crimes that would have been avoided if all states had eased their permit laws in 1992, according to Lott and Mustard's model. Reviewers at the National Research Council concluded, however, that very tiny changes to the model created large variations in outcomes—either weakening or strengthening the link between permit laws and crime—so it was impossible to say with their model how permit law changes affect crime.

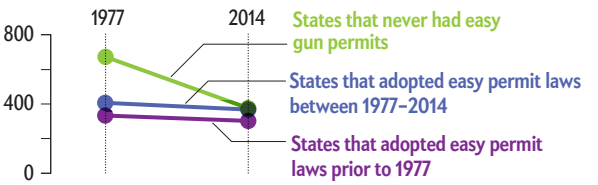
Projected Change in Number of Crimes If States without Easier Permit Laws in 1992 Had Adopted Such Laws (Estimates Using County-Level Data)



Contradictory Work

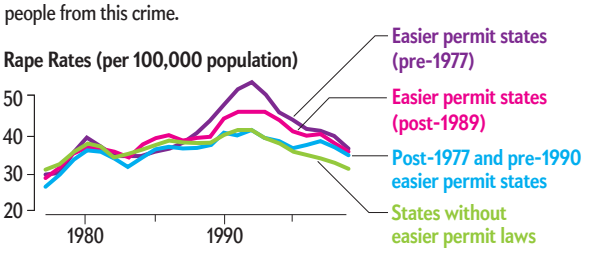
Research published this year explicitly gainsays Lott and Mustard's model. Economist John Donohue of Stanford University found that violent crime rates dropped dramatically in states that did not have easy-to-obtain gun permits but decreased just a little in states that allowed such permits.

Violent Crime Rates (per 100,000 residents)



Focusing on rape in a 2003 study, Donohue and his colleagues found no protective effect in states that made it easier to carry guns. Over a decade such states had similar or higher rape rates than did states that never eased gun permit laws. Laws that made it easier to carry guns did not protect people from this crime.

Rape Rates (per 100,000 population)



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Council, which provides independent advice on scientific issues, turned its attention to firearm research, including Lott's findings. It asked 15 scholars to reanalyze Lott's data because "there was such a conflict in the field about the findings," recalls panel chair and criminologist Charles Wellford, now a professor emeritus at the University of Maryland. Lott's models, they found, could be tweaked in tiny ways to produce big changes in results. "The analyses that we did, and that others have done, show that these estimates are very fragile," Wellford explains. "The committee, with one exception, concluded that you could not accept his conclusion that more guns meant less crime." Wintemute summarized it this way: "There are a few studies that suggest that liberalizing access to concealed firearms has, on balance, beneficial effects. There are a far larger number of studies that suggest that it has, on balance, detrimental effects."

OFF TARGET: This progun shirt, along with bumper stickers advocating that guns protect good people from crime, reflects a sentiment undercut by dozens of studies showing firearms are poor deterrents.

Lott, who now runs the nonprofit Crime Prevention Research Center, says the panel was biased and "set up to try to go against my work." The NRA takes a related tack: it says research highlighting the danger of weapons is part of a gun-control agenda to confiscate firearms.

It is crucial, though, to distinguish the leadership of progun organizations from their constituents, who often have more nuanced opinions. "I do own a firearm, I'm licensed, I'm actually able to train others in using a firearm—and my goal in life is to never, ever, ever have to use it," says Tina Monaghan, a city clerk in Nelson, Ga. (In 2013 Nelson, like Kennesaw, passed a law mandating that residents own guns, but the ordinance was relaxed later that year in response to a lawsuit.) According to a 2015 survey published by Johns Hopkins University researchers, 85 percent of gun owners support background checks for all gun sales, including sales through unlicensed dealers—even though the NRA strongly opposes them.

I HEARD A LOT MORE about divergence from NRA positions on my last stop in Alabama: Scottsboro Gun and Pawn, a shop perched at the end of Broad Street, one of the town's main drags. The co-owner, Robert Shook, told me about the ongoing push in the Alabama State Senate to eliminate concealed carry permits altogether, a move that would make it legal for anyone older than 18 to carry a hidden gun. (The bill passed in the Alabama Senate in April of this year but did not come up for a vote in the state's House of Representatives during the 2017 session.) "There's a lot of stuff that the NRA does that I don't agree with," he said, standing behind a glass case filled with handguns. "They've gone farther right than the other side left. They're throwing common sense out the window." Indeed, the NRA of today is actually more extreme than the organization used to be. In the 1930s NRA president Karl Frederick testified in Congress in support of the National Firearms Act, which restricted concealed carrying. "I do not believe in the general promiscuous toting of guns," Frederick said.

The belief that more guns lead to fewer crimes is founded on the idea that guns are dangerous when bad guys have them, so we should get more guns into the hands of good guys. Yet Cook, the Duke economist, says this good guy/bad guy dichotomy is a false and dangerous one. Even upstanding American citizens are only human—they can "lose their temper, or exercise poor judgment, or misinterpret a situation, or have a few drinks," he explains, and if they're carrying guns when they do, bad things can ensue. In 2013 in Ionia, Mich., a road rage incident led two drivers—both concealed carry permit holders—to get out of their cars, take out their guns and kill each other.

As I drove from Scottsboro to Atlanta to catch my flight home, I kept turning over what I had seen and learned. Although we do not yet know *exactly* how guns affect us, the notion that more guns lead to less crime is almost certainly incorrect. The research on guns is not uniform, and we could certainly use more of it. But when all but a few studies point in the same direction, we can feel confident that the arrow is aiming at the truth—which is, in this case, that guns do not inhibit crime and violence but instead make it worse.

The popular gun-advocacy bumper sticker says that "guns don't kill people, people kill people"—and it is, in fact, true. People, all of us, lead complicated lives, misinterpret situations, get angry, make mistakes. And when a mistake involves pulling a trigger, the damage can't be undone. Unlike my Glock-aided attack on the zombie at the gun range, life is not target practice. SA

Longtime contributor and writer **Melinda Wenner Moyer** won an Award for Excellence in Health Care Journalism for her December 2016 *Scientific American* article "The Looming Threat of Factory-Farm Superbugs."

MORE TO EXPLORE

Obstacles to Firearm and Violence Research. Arthur L. Kellermann in *Health Affairs,* Vol. 12, No. 4, pages 142–153; November 1993.

Armed Resistance to Crime: The Prevalence and Nature of Self-Defense with a Gun. Gary Kleck and Marc Gertz in *Journal of Criminal Law and Criminology,* Vol. 86, No. 1, pages 150–187; 1995.

Crime, Deterrence, and Right-to-Carry Concealed Handguns. John R. Lott, Jr., and David B. Mustard in *Journal of Legal Studies,* Vol. 26, No. 1, pages 1–68; January 1997.

Firearms and Violence: A Critical Review. National Research Council. National Academies Press, 2004.

State-Level Homicide Victimization Rates in the US in Relation to Survey Measures of Household Firearm Ownership, 2001–2003. Matthew Miller et al. in *Social Science & Medicine,* Vol. 64, No. 3, pages 656–664; February 2007.

The Relationship between Gun Ownership and Stranger and Nonstranger Firearm Homicide Rates in the United States, 1981–2010. Michael Siegel et al. in *American Journal of Public Health,* Vol. 104, No. 10, pages 1912–1919; October 2014.

Is It a Dangerous World Out There? The Motivational Bases of American Gun Ownership. Wolfgang Stroebe et al. in *Personality and Social Psychology Bulletin,* Vol. 43, No. 8, pages 1071–1085; August 2017.

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SOURCES: "CRIME, DETERRENCE, AND RIGHT-TO-CARRY CONCEALED HANDGUNS," BY JOHN R. LOTT, JR., AND DAVID B. MUSTARD, IN *JOURNAL OF LEGAL STUDIES*, VOL. 26, NO. 1; JANUARY 1997; "RIGHT-TO-CARRY LAWS AND VIOLENT CRIME: A COMPREHENSIVE ASSESSMENT USING PANEL DATA AND A STATE-LEVEL SYNTHETIC CONTROLS ANALYSIS," BY JOHN J. DONOHUE, ABHAY ANEJA AND KYLE D. WEBER. NATIONAL BUREAU OF ECONOMIC RESEARCH WORKING PAPER NO. 23510. JUNE 2017; "SHOOTING DOWN THE 'MORE GUNS, LESS CRIME' HYPOTHESIS," BY IAN AYRES AND JOHN J. DONOHUE III, IN *STANFORD LAW REVIEW*, VOL. 55; APRIL 2003

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A PLAN TO PREVENT GUN SUICIDES

Firearm sellers have become unlikely allies of public health authorities in the effort to keep people from killing themselves

By Nancy Shute

RALPH DEMICCO FEELS AS IF HE HAS WATCHED THE 53-MINUTE SURVEILLANCE video 100 times, searching it for clues to preventing tragedy. He sees a young man walk into his gun shop in Hooksett, N.H. The man asks about buying a handgun. "He engaged the clerk in small talk, totally disarmed the clerk," Demicco says. "No way in heck that clerk would suspect that three quarters of an hour after the conversation that person would take his life."

And yet the 24-year-old man did kill himself, pulling the trigger soon after leaving the boxy beige building. Nor was he the only customer who did so. In one awful week in 2009, he and two other people came into the shop, which Demicco no longer owns, bought guns and used the purchases shortly thereafter to kill themselves.

The experience shook Demicco and prompted him to help found a movement that links members of the firearm community with public health experts to prevent suicides by raising awareness about gun safety, among other things. Its leaders are realists who accept that very strict, European-style gun control is not politically feasible in the U.S. and would, in any case, be a nonstarter for most gun sellers, who oppose such control. But they also know that households that keep guns and ammunition in separate, locked locations and store their guns unloaded have much lower risks of accidental or intentional deaths from firearms. In addition, as a further safety measure, the group seeks to make it socially acceptable for relatives and friends to offer to hold on to a potentially suicidal gun owner's weapons until the crisis has passed.

The public safety campaign is admittedly modest so far, consisting mainly of distributing posters and brochures about suicide to gun shops. Still, its start in a state whose motto is "Live Free or Die" shows that the long-standing political stalemate over gun-control laws need not prevent progress from being made.

EVIDENCE-BASED APPROACH

THE GUN SAFETY COALITION is motivated by data as well as by the distressing stories of gun shop owners. In the case of guns, the impulsive nature of many suicides, combined with the lethal efficiency of firearms, creates an exceptionally deadly pattern.

Several studies now confirm that suicide is often a decision made suddenly. If the moment somehow passes safely, the evidence suggests, lives can be saved in the short and long term.

"There's a fair amount of research showing that the suicide crisis is time-limited," says John Mann, a professor of translational neuroscience at Columbia University who studies suicide. Two thirds of those who survived a suicide attempt, according to one 1991 study, had started planning their course of action less than an hour beforehand. Another study notes that almost half of the 82 people who attempted suicide said they had started thinking about their current attempt less than 10 minutes earlier. Moreover, in the case of guns especially, an investigation by the New Hampshire medical examiner's office showed that nearly one in 10 suicides by firearm from 2007 to 2009 involved a weapon that was purchased or rented the preceding week—often within just a few hours.

National data speak to the other half of this deadly combination. Although guns are not the most popular way that people try to take their life (this dubious distinction belongs to pills), they

Illustration by Kyle Smart

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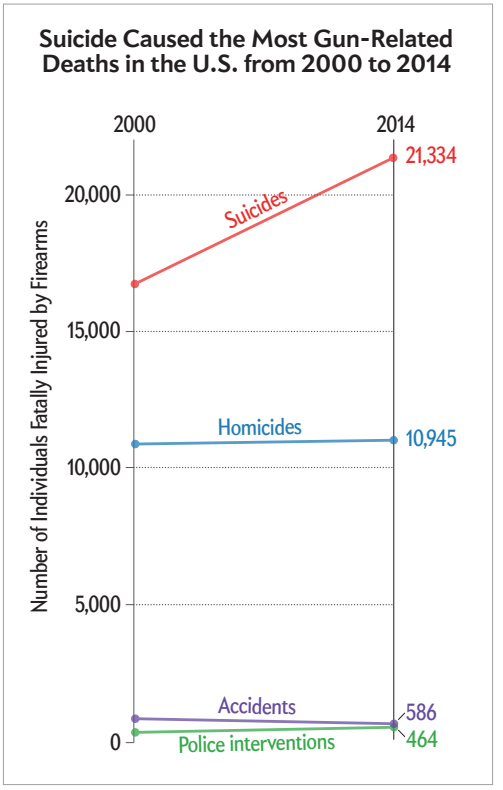
are the most deadly. Statistics show that 85 percent of attempts with a gun are fatal, compared with 69 percent for hanging and 2 percent for self-poisoning. Mass shootings and murders dominate the news, but 21,334—or nearly two thirds—of the 33,599 gun deaths that occurred in the U.S. in 2014 were suicides. Another 10,945 were homicides.

Guns, then, take what is often an ambivalent decision and turn it into an irrevocable one.

Won't people who are stopped from killing themselves today just find another way to complete the act later? Some number will, unfortunately. Yet most who survive do not keep trying until they succeed. Instead, studies show, the majority of survivors die a natural death many years after failing to kill themselves. The period of greatest vulnerability seems to be in the first year after an attempt, a time when treatment for those who try to end their life is critically important, experts say.



SOURCE: CENTERS FOR DISEASE CONTROL AND PREVENTION

Perhaps the best evidence for the strength of this survival instinct stems from pioneering research carried out by Richard Seiden in the 1970s. Then a clinical psychologist at the University of California, Berkeley, Seiden found that more than 90 percent of the 515 people who were prevented from jumping off the Golden Gate Bridge between the year it opened in 1937 and 1971 eventually lived long enough to die of nonviolent causes. Indeed, Seiden's work spurred such a surge of scientific inquiry by other investigators who reached the same conclusion that state authorities finally agreed to install antisuicide netting underneath the famous span. Construction on the barrier has begun and is scheduled to finish sometime in 2021.

LIFESAVING RESTRICTIONS

FIGURING OUT WAYS to limit access to particularly lethal methods of committing suicide—whether they are bridges or guns—makes sense from a public health point of view. Yet it also made sense to Demicco and a few other gun shop owners in New Hampshire, who agreed to collaborate with mental health practitioners and researchers after that devastating rash of suicides in 2009. When a public health researcher expressed surprise at the positive response from the firearm community, "a firearm instructor said, 'I could be insulted by that,'" says Elaine Frank, who directs the Counseling on Access to Lethal Means project at Children's Hospital at Dartmouth-Hitchcock and is co-chair of the New Hampshire Firearm Safety Coalition. "'Why do you think the firearm community would be less interested in preventing suicide than you would be?'" In 2011 the group sent posters and brochures to New Hampshire's 65 retail gun shops. The goal was to encourage customers to become alert to signs of crisis in friends or household members and to make firearms inaccessible until the crisis had passed.

"Concerned about a family member or friend?" one poster asks. "Suicides in NH far outnumber homicides." In the photograph, one gray-haired man rests his hand on the shoulder of another. A handgun lies on the kitchen table between them. "Hold on to their guns," the poster continues. "Putting time and distance between a suicidal person and a gun may save a life."

The leaders of the New Hampshire effort did not expect their social-marketing campaign to have a significant effect on the number of suicides right away—and it did not. But 48 percent of the gun shops throughout the state still had the handouts and other materials available for customers after the first year, according to a study published in 2015 in the journal *Suicide and Life-Threatening Behavior*. "That's actually a pretty incredible uptake, especially for a topic like suicide," says Catherine Barber of the Harvard Injury Control Research Center, who is a co-author of the study, along with her colleague Mary Vriniotis, Frank, Demicco and the rest of the New Hampshire Firearm Safety Coalition. "Glancing at one poster isn't going to do the trick," Barber says. "That's like one time seeing a poster about designated drivers. But hopefully it's lighting a match."

Since the New Hampshire project's inception, the model has been adopted or adapted in more than a dozen states, each of which must tailor the concept to its political and legal realities. In Massachusetts, for example, only someone licensed to possess firearms could legally take a weapon for safekeeping, but attaching a trigger lock and giving the key to a trusted friend or relative would accomplish the same purpose.

Utah, which at 21 deaths per 100,000 people has one of the highest rates of suicide in the U.S., is training staff at hospitals and doctors' offices to screen patients for suicide risk and to intervene appropriately. Clark Aposhian, head of the influential Utah Shooting Sports Council, says his group is developing public service announcements aimed at encouraging friends and family of struggling loved ones to get some distance from firearms. "Go over to their house, kind of like a mini intervention at the door," Aposhian suggests. "Put your arm around them and say, 'Let me babysit your guns for a while.'"

It is still too early to know what impact these efforts have had in Utah or elsewhere. But research indicates that Aposhian, Demicco and fellow gun enthusiasts are taking the right steps. Perhaps, as is true of the movement that formed around the slogan "Friends don't let friends drive drunk," championing the safeguarding of guns as a way to reduce suicides will pick up steam in the years ahead. SA

Nancy Shute is a science journalist at NPR. Follow her on Twitter @nancyshute

Graphic by Amanda Montañez

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Gun Science

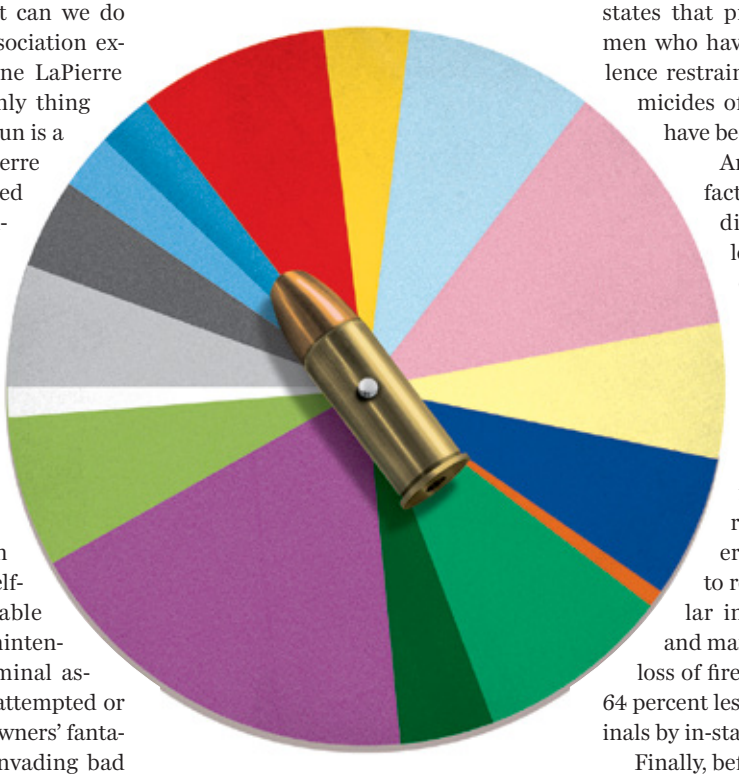
How data can clarify the gun-control debate

By Michael Shermer

ACCORDING TO the Centers for Disease Control and Prevention, 33,594 people died by guns in 2014 (the most recent year for which U.S. figures are available), a staggering number that is orders of magnitude higher than that of comparable Western democracies. What can we do about it? National Rifle Association executive vice president Wayne LaPierre believes he knows: "The only thing that stops a bad guy with a gun is a good guy with a gun." If LaPierre means professionally trained police and military who routinely practice shooting at ranges, this observation would at least be partially true. If he means armed private citizens with little to no training, he could not be more wrong.

Consider a 1998 study in the *Journal of Trauma and Acute Care Surgery* that found that "every time a gun in the home was used in a self-defense or legally justifiable shooting, there were four unintentional shootings, seven criminal assaults or homicides, and 11 attempted or completed suicides." Pistol owners' fantasy of blowing away home-invading bad guys or street toughs holding up liquor stores is a myth debunked by the data showing that a gun is 22 times more likely to be used in a criminal assault, an accidental death or injury, a suicide attempt or a homicide than it is for self-defense. I harbored this belief for the 20 years I owned a Ruger .357 Magnum with hollow-point bullets designed to shred the body of anyone who dared to break into my home, but when I learned about these statistics, I got rid of the gun.

More insights can be found in a 2013 book from Johns Hopkins University Press entitled *Reducing Gun Violence in America: Informing Policy with Evidence and Analysis,* edited by Daniel W. Webster and Jon S. Vernick, both professors in health policy and management at the Johns Hopkins Bloomberg School of Public Health. In addition to the 31,672 people killed by guns in 2010, another 73,505 were treated in hospital emergency rooms for nonfatal bullet wounds, and 337,960 nonfatal violent crimes were committed with guns. Of those 31,672 dead, 61 percent were suicides, and the vast majority of the rest were homicides by people who knew one another.



For example, of the 1,082 women and 267 men killed in 2010 by their intimate partners, 54 percent were shot by guns. Over the past quarter of a century, guns were involved in a greater number of intimate partner homicides than all other causes combined. When a woman is murdered, it is most likely by her intimate partner with a gun. Regardless of what really caused Olympic track star Oscar Pistorius to shoot his girlfriend, Reeva Steenkamp (whether he mistook her for an intruder or he snapped in a lover's quarrel), her death is only the latest such headline. Recall, too, the fate of Nancy Lanza, killed by her own gun in her own home in Connecticut by her son, Adam Lanza, before he went to Sandy Hook Elementary School to murder some two dozen children and adults. As an alternative to arming women against violent men, legislation can help: data show that in states that prohibit gun ownership by men who have received a domestic violence restraining order, gun-caused homicides of intimate female partners have been reduced by 25 percent.

Another myth to fall to the facts is that gun-control laws disarm good people and leave the crooks with weapons. Not so, say the Johns Hopkins authors: "Strong regulation and oversight of licensed gun dealers—defined as having a state law that required state or local licensing of retail firearm sellers, mandatory record keeping by those sellers, law enforcement access to records for inspection, regular inspections of gun dealers, and mandated reporting of theft of loss of firearms—was associated with 64 percent less diversion of guns to criminals by in-state gun dealers."

Finally, before we concede civilization and arm everyone to the teeth *pace* the NRA, consider the primary cause of the centuries-long decline of violence as documented by Steven Pinker in his 2011 book *The Better Angels of Our Nature:* the rule of law by states that turned over settlement of disputes to judicial courts and curtailed private self-help justice through legitimate use of force by police and military trained in the proper use of weapons. SA

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His latest book is *Heavens on Earth* (Henry Holt, 2018). Follow him on Twitter @michaelshermer

Illustration by Doug Chayka

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food

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The human race has selectively bred crops to suit our needs for thousands of years. People have consumed as many as several trillion meals containing genetically modified (GM) ingredients over the past few decades. Not a single verified case of illness has ever been attributed to the genetic alterations. But skepticism surrounding GM crops remains—especially in European nations—and is a detriment to millions who might otherwise benefit from them. The perks of GM crops greatly outweigh the health risks, which so far remain theoretical, our authors say (*page 76*). In fact, more than 130 research findings over 25 years have shown that GM organisms are not more risky than other plant-breeding techniques (*page 92*). But ramping up agricultural output by an estimated 70 percent to feed an exploding global population most likely cannot rely on GM foods alone. New techniques are harnessing the power of the plant phytobiome to create foods that grow faster and resist pests and other environmental harms (*page 84*).

GETTY IMAGES

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are engineered foods evil?

Proponents of genetically modified crops say the technology is the only way to feed a warming, increasingly populous world. Critics say we tamper with nature at our peril. Who is right?

By David H. Freedman

ROBERT GOLDBERG SAGS INTO HIS DESK CHAIR AND gestures at the air. "Frankenstein monsters, things crawling out of the lab," he says. "This the most depressing thing I've ever dealt with."

Goldberg, a plant molecular biologist at the University of California, Los Angeles, is not battling psychosis. He is expressing despair at the relentless need to confront what he sees as bogus fears over the health risks of genetically modified (GM) crops. Particularly frustrating to him, he says, is that this debate should have ended decades ago, when researchers produced a stream of exonerating evidence: "Today we're facing the same objections we faced 40 years ago."

Across campus, David Williams, a cellular biologist who specializes in vision, has the opposite complaint. "A lot of naive science has been involved in pushing this technology," he says. "Thirty years ago we didn't know that when you throw any gene into a different genome, the genome reacts to it. But now anyone in this field knows the genome is not a static environment. Inserted genes can be transformed by several different means, and it can happen generations later." The re-

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sult, he insists, could very well be potentially toxic plants slipping through testing.

Williams concedes that he is among a tiny minority of biologists raising sharp questions about the safety of GM crops. But he says this is only because the field of plant molecular biology is protecting its interests. Funding, much of it from the companies that sell GM seeds, heavily favors researchers who are exploring ways to further the use of genetic modification in agriculture. He says that biologists who point out health or other risks associated with GM crops—who merely report or defend experimental findings that imply there may be risks—find themselves the focus of vicious attacks on their credibility, which leads scientists who see problems with GM foods to keep quiet.

Whether Williams is right or wrong, one thing is undeniable: despite overwhelming evidence that GM crops are safe to eat, the debate over their use continues to rage, and in some parts of the world, it is growing ever louder. Skeptics would argue that this contentiousness is a good thing—that we cannot be too cautious when tinkering with the genetic basis of the world's food supply. To researchers such as Goldberg, however, the persistence of fears about GM foods is nothing short of exasperating. "In spite of hundreds of millions of genetic experiments involving every type of organism on earth," he says, "and people eating billions of meals without a problem, we've gone back to being ignorant."

So who is right: advocates of GM or critics? When we look carefully at the evidence for both sides and weigh the risks and benefits, we find a surprisingly clear path out of this dilemma.

BENEFITS AND WORRIES

THE BULK OF THE SCIENCE on GM safety points in one direction. Take it from David Zilberman, a U.C. Berkeley agricultural and environmental economist and one of the few researchers considered credible by both agricultural chemical companies and their critics. He argues that the benefits of GM crops greatly outweigh the health risks, which so far remain theoretical. The use of GM crops "has lowered the price of food," Zilberman says. "It has increased farmer safety by allowing them to use less pesticide. It has raised the output of corn, cotton and soy by 20 to 30 percent, allowing some people to survive who would not have without it. If it were more widely adopted around the world, the price [of food] would go lower, and fewer people would die of hunger."

In the future, Zilberman says, those advantages will become all the more significant. The United Nations Food and Agriculture Organization estimates that the world will have to grow 70 percent more food by 2050 just to keep up with population growth. Climate change will make much of the world's arable land more difficult to farm. GM crops, Zilberman says, could produce higher yields, grow in dry and salty land, withstand high and low temperatures, and tolerate insects, disease and herbicides.

Despite such promise, much of the world has been busy banning, restricting and otherwise shunning GM foods. Nearly all the corn and soybeans grown in the U.S. are genetically modified, but only two GM crops, Monsanto's MON810 maize and BASF's Amflora potato, are accepted in the European Union. Ten E.U. nations have banned MON810, and although BASF withdrew Amflora from the market in 2012, four E.U. nations have taken the trouble to ban that, too. Approval of a few new GM corn strains has been proposed there, but so far it has been repeatedly and soundly voted down. Throughout Asia, including in India and China, governments have yet to approve most GM crops, including an insect-resistant rice that produces higher yields with less pesticide. In Africa, where millions go hungry, several nations have refused to import GM foods in spite of their lower costs (the result of higher yields and a reduced need for water and pesticides). Kenya has banned them altogether amid widespread malnutrition. No country has definite plans to grow Golden Rice, a crop engineered to deliver more vitamin A than spinach (rice normally has no vitamin A), even though vitamin A deficiency causes more than one million deaths annually and half a million cases of irreversible blindness in the developing world.

Globally, only a tenth of the world's cropland includes GM plants. Four countries—the U.S., Canada, Brazil and Argentina—grow 90 percent of the planet's GM crops. Other Latin American countries are pushing away from the plants. And even in the U.S., voices decrying genetically modified foods are becoming louder. In 2016 the U.S. federal government passed a law requiring labeling of GM ingredients in food products, replacing GM-labeling laws in force or proposed in several dozen states.

The fear fueling all this activity has a long history. The public has been worried about the safety of GM foods since scientists at the University of Washington developed the first genetically modified tobacco plants in the 1970s. In the mid-1990s, when the first GM crops reached the market, Greenpeace, the Sierra Club, Ralph Nader, Prince Charles and a number of celebrity chefs took highly visible stands against them. Consumers in Europe became particularly alarmed: a survey conducted in 1997, for example, found that 69 percent of the Austrian public saw serious risks in GM foods, compared with only 14 percent of Americans.

In Europe, skepticism about GM foods has long been bundled with other concerns, such as a resentment of American agribusiness. Whatever it is based on, however, the European attitude reverberates across the world, influencing policy in countries where GM crops could have tremendous benefits. "In Africa, they don't care what us savages in America are doing," Zilberman says. "They look to Europe and see countries there rejecting GM, so they don't use it." Forces fighting genetic modification in Europe have rallied support for "the precautionary principle," which holds that given the kind of catastrophe that would emerge from loosing a toxic, invasive GM crop on the world, GM efforts should be shut down until the technology is proved absolutely safe.

But as medical researchers know, nothing can really be "proved safe." One can only fail to turn up significant risk after trying hard to find it—as is the case with GM crops.

IN BRIEF

The vast majority of the research on genetically modified (GM) crops suggests that they are safe to eat and that they have the potential to feed millions of people worldwide who currently go hungry. **Yet not all criticisms** of GM are so easily rejected, and pro-GM scientists are often dismissive and even unscientific in their rejection of the counterevidence. **A careful analysis** of the risks and benefits argues for expanded deployment *and* safety testing of GM crops.

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How to Build a Better Plant

Genetic modification and conventional plant breeding have much in common: both are ways of producing new crops by altering plant genomes. The differences have to do with the tools used, the number of genes swapped and the comfort level of the average consumer.

Conventional Crossbreeding

Since the earliest days of agriculture, humans have been selecting plants with desirable characteristics and cross-breeding them to make new, even more desirable specimens—in this case, a tomato plant that combines the blight resistance of one parent with the high fruit yield of another.

Genetic Modification

In the 1970s scientists began developing methods for quickly inserting specific genes from one plant into the DNA of another—a quick, targeted means to the same end as conventional crossbreeding. Early researchers used disarmed *Agrobacterium* to smuggle genes into plant cells. Later, scientists at Cornell University developed the DNA particle gun method, in which engineers shoot DNA-coated tungsten balls through the cell walls of the target plant by firing them out of a blank gunpowder cartridge.

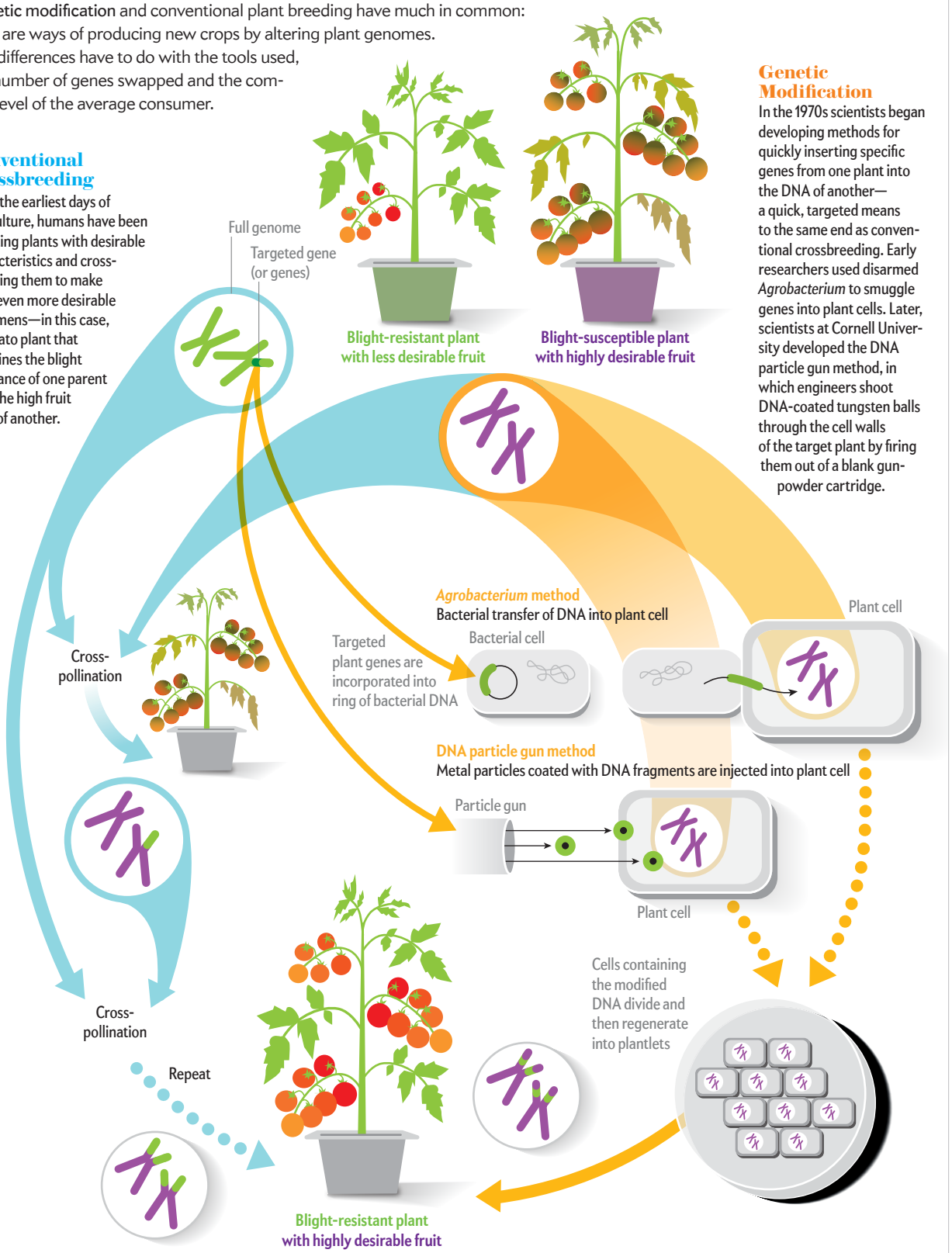
Full genome
Targeted gene (or genes)
Blight-resistant plant with less desirable fruit
Blight-susceptible plant with highly desirable fruit
Cross-pollination
Agrobacterium method
Bacterial transfer of DNA into plant cell
Bacterial cell
Plant cell
Targeted plant genes are incorporated into ring of bacterial DNA
DNA particle gun method
Metal particles coated with DNA fragments are injected into plant cell
Particle gun
Plant cell
Cells containing the modified DNA divide and then regenerate into plantlets
Cross-pollination
Repeat
Blight-resistant plant with highly desirable fruit

Illustration by Jen Christiansen

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A CLEAN RECORD

THE HUMAN RACE has been selectively breeding crops, thus altering plants' genomes, for millennia. Ordinary wheat has long been strictly a human-engineered plant; it could not exist outside of farms, because its seeds do not scatter. For some 60 years scientists have been using "mutagenic" techniques to scramble the DNA of plants with radiation and chemicals, creating strains of wheat, rice, peanuts and pears that have become agricultural mainstays. The practice has inspired little objection from scientists or the public and has caused no known health problems.

The difference is that selective breeding or mutagenic techniques tend to result in large swaths of genes being swapped or altered. GM technology, in contrast, enables scientists to insert into a plant's genome a single gene (or a few of them) from another species of plant or even from a bacterium, virus or animal. Supporters argue that this precision makes the technology much less likely to produce surprises. Most plant molecular biologists also say that in the highly unlikely case that an unexpected health threat emerged from a new GM plant, scientists would quickly identify and eliminate it. "We know where the gene goes and can measure the activity of every single gene around it," Goldberg says. "We can show exactly which changes occur and which don't."

And although it might seem creepy to add virus DNA to a plant, doing so is, in fact, no big deal, proponents say. Viruses have been inserting their DNA into the genomes of crops, as well as humans and all other organisms, for millions of years. They often deliver the genes of other species while they are at it, which is why our own genome is loaded with genetic sequences that originated in viruses and nonhuman species. "When GM critics say that genes don't cross the species barrier in nature, that's just simple ignorance," says Alan McHughen, a plant molecular geneticist at U.C. Riverside. Pea aphids contain fungi genes. Triticale is a century-plus-old hybrid of wheat and rye found in some flours and breakfast cereals. Wheat itself, for that matter, is a cross-species hybrid. "Mother Nature does it all the time, and so do conventional plant breeders," McHughen says.

Could eating plants with altered genes allow new DNA to work its way into our own? It is possible but hugely improbable. Scientists have never found genetic material that could survive a trip through the human gut and make it into cells. Besides, we are routinely exposed to—and even consume—the viruses and bacteria whose genes end up in GM foods. The bacterium *Bacillus thuringiensis,* for example, which produces proteins fatal to insects, is sometimes enlisted as a natural pesticide in organic farming. "We've been eating this stuff for thousands of years," Goldberg says.

In any case, proponents say, people have consumed as many as trillions of meals containing genetically modified ingredients over the past few decades. Not a single verified case of illness has ever been attributed to the genetic alterations. Mark Lynas, a prominent anti-GM activist who in 2013 publicly switched to strongly supporting the technology, has pointed out that every single news-making food disaster on record has been attributed to non-GM crops, such as the *Escherichia coli*–infected organic bean sprouts that killed 53 people in Europe in 2011.

Critics often disparage U.S. research on the safety of genetically modified foods, which is often funded or even conducted by GM companies, such as Monsanto. But much research on the subject comes from the European Commission, the administrative body of the E.U., which cannot be so easily dismissed as an industry tool. The European Commission has funded 130 research projects, carried out by more than 500 independent teams, on the safety of GM crops. None of those studies found any special risks from GM crops.

Plenty of other credible groups have arrived at the same conclusion. Gregory Jaffe, director of biotechnology at the Center for Science in the Public Interest, a science-based consumer-watchdog group in Washington, D.C., takes pains to note that the center has no official stance, pro or con, with regard to genetically modifying food plants. Yet Jaffe insists the scientific record is clear. "Current GM crops are safe to eat and can be grown safely in the environment," he says. The American Association for the Advancement of Science, the American Medical Association and the National Academy of Sciences have all unreservedly backed GM crops. The U.S. Food and Drug Administration, along with its counterparts in several other countries, has repeatedly reviewed large bodies of research and concluded that GM crops pose no unique health threats. Dozens of review studies carried out by academic researchers have backed that view.

Opponents of genetically modified foods point to a handful of studies indicating possible safety problems. But reviewers have dismantled almost all of those reports. For example, a 1998 study by plant biochemist Árpád Pusztai, then at the Rowett Institute in Scotland, found that rats fed a GM potato suffered from stunted growth and immune system–related changes. But the potato was not intended for human consumption—it was, in fact, designed to be toxic for research purposes. The Rowett Institute later deemed the experiment so sloppy that it refuted the findings and charged Pusztai with misconduct.

Similar stories abound. Most recently, a team led by Gilles-Éric Séralini, a researcher at the University of Caen Lower Normandy in France, found that rats eating a common type of GM corn contracted cancer at an alarmingly high rate. But Séralini has long been an anti-GM campaigner, and critics charged that in his study, he relied on a strain of rat that too easily develops tumors, did not use enough rats, did not include proper control groups and failed to report many details of the experiment, including how the analysis was performed. After a review, the European Food Safety Authority dismissed the study's findings. Several other European agencies came to the same conclusion. "If GM corn were that toxic, someone would have noticed by now," McHughen says. "Séralini has been refuted by everyone who has cared to comment."

Some scientists say the objections to GM food stem from politics rather than science—that they are motivated by an objection to large multinational corporations having enormous influence over the food supply; invoking risks from genetic modification just provides a convenient way of whipping up the masses against industrial agriculture. "This has nothing to do with science," Goldberg says. "It's about ideology." Former anti-GM activist Lynas agrees. He has gone as far as labeling the anti-GM crowd "explicitly an antiscience movement."

PERSISTENT DOUBTS

NOT ALL OBJECTIONS to genetically modified foods are so easily dismissed, however. Long-term health effects can be subtle and nearly impossible to link to specific changes in the environment. Scientists have long believed that Alzheimer's disease and

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many cancers have environmental components, but few would argue we have identified all of them.

And opponents say that it is not true that the GM process is less likely to cause problems simply because fewer, more clearly identified genes are replaced. David Schubert, an Alzheimer's researcher who heads the Cellular Neurobiology Laboratory at the Salk Institute for Biological Studies in La Jolla, Calif., asserts that a single, well-characterized gene can still settle in the target plant's genome in many different ways. "It can go in forward, backward, at different locations, in multiple copies, and they all do different things," he says. And as U.C.L.A.'s Williams notes, a genome often continues to change in the successive generations after the insertion, leaving it with a different arrangement than the one intended and initially tested. There is also the phenomenon of "insertional mutagenesis," Williams adds, in which the insertion of a gene ends up quieting the activity of nearby genes.

True, the number of genes affected in a GM plant most likely will be far, far smaller than in conventional breeding techniques. Yet opponents maintain that because the wholesale swapping or alteration of entire packages of genes is a natural process that has been happening in plants for half a billion years, it tends to produce few scary surprises today. Changing a single gene, on the other hand, might turn out to be a more subversive action, with unexpected ripple effects, including the production of new proteins that might be toxins or allergens.

Opponents also point out that the kinds of alterations caused by the insertion of genes from other species might be more impactful, more complex or more subtle than those caused by the intraspecies gene swapping of conventional breeding. And just because there is no evidence to date that genetic material from an altered crop can make it into the genome of people who eat it does not mean such a transfer will never happen—or that it has not already happened and we have yet to spot it. These changes might be difficult to catch; their impact on the production of proteins might not even turn up in testing. "You'd certainly find out if the result is that the plant doesn't grow very well," Williams says. "But will you find the change if it results in the production of proteins with long-term effects on the health of the people eating it?"

It is also true that many pro-GM scientists in the field are unduly harsh—even unscientific—in their treatment of critics. GM proponents sometimes lump every scientist who raises safety questions together with activists and discredited researchers. And even Séralini, the scientist behind the study that found high cancer rates for GM-fed rats, has his defenders. Most of them are nonscientists, or retired researchers from obscure institutions, or nonbiologist scientists, but the Salk Institute's Schubert also insists the study was unfairly dismissed. He says that as someone who runs drug-safety studies, he is well versed on what constitutes a good-quality animal toxicology study and that Séralini's makes the grade. He insists that the breed of rat in the study is commonly used in respected drug studies, typically in numbers no greater than in Séralini's study; that the methodology was standard; and that the details of the data analysis are irrelevant because the results were so striking.

Schubert joins Williams as one of a handful of biologists from respected institutions who are willing to sharply challenge the GM-foods-are-safe majority. Both charge that more scientists would speak up against genetic modification if doing so did not invariably lead to being excoriated in journals and the media. These attacks, they argue, are motivated by the fear that airing doubts could lead to less funding for the field. Says Williams: "Whether it's conscious or not, it's in their interest to promote this field, and they're not objective."

Both scientists say that after publishing comments in respected journals questioning the safety of GM foods, they became the victims of coordinated attacks on their reputations. Schubert even charges that researchers who turn up results that might raise safety questions avoid publishing their findings out of fear of repercussions. "If it doesn't come out the right way," he says, "you're going to get trashed."

There is evidence to support that charge. In 2009 *Nature* detailed the backlash to a reasonably solid study published in the *Proceedings of the National Academy of Sciences USA* by researchers from Loyola University Chicago and the University of Notre Dame. The paper showed that GM corn seemed to be finding its way from farms into nearby streams and that it might pose a risk to some insects there because, according to the researchers' lab studies, caddis flies appeared to suffer on diets of pollen from GM corn. Many scientists immediately attacked the study, some of them suggesting the researchers were sloppy to the point of misconduct.

A WAY FORWARD

THERE IS A MIDDLE GROUND in this debate. Many moderate voices call for continuing the distribution of GM foods while maintaining or even stepping up safety testing on new GM crops. They advocate keeping a close eye on the health and environmental impact of existing ones. But they do not single out GM crops for special scrutiny, the Center for Science in the Public Interest's Jaffe notes: *all* crops could use more testing. "We should be doing a better job with food oversight altogether," he says.

Even Schubert agrees. In spite of his concerns, he believes future GM crops can be introduced safely if testing is improved. "Ninety percent of the scientists I talk to assume that new GM plants are safety-tested the same way new drugs are by the FDA," he says. "They absolutely aren't, and they absolutely should be."

Stepped-up testing would pose a burden for GM researchers, and it could slow down the introduction of new crops. "Even under the current testing standards for GM crops, most conventionally bred crops wouldn't have made it to market," McHughen says. "What's going to happen if we become even more strict?"

That is a fair question. But with governments and consumers increasingly coming down against GM crops altogether, additional testing may be the compromise that enables the human race to benefit from those crops' significant advantages. SA

David H. Freedman has been covering science, business and technology for more than 30 years. His 2010 book *Wrong* explores the forces that cause scientists and other experts to mislead us.

MORE TO EXPLORE

Food, Inc.: Mendel to Monsanto—The Promises and Perils of the Biotech Harvest. Peter Pringle. Simon & Schuster, 2003.

Tough Lessons from Golden Rice. Martin Enserink in *Science,* Vol. 320, pages 468–471; April 25, 2008.

Case Studies: A Hard Look at GM Crops. Natasha Gilbert in *Nature,* Vol. 497, pages 24–26; May 2, 2013. www.nature.com/news/case-studies-a-hard-look-at-gm-crops-1.12907

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THE "TRUE" HUMAN DIET

From the standpoint of paleoecology, the so-called Paleo diet is a myth

By Peter S. Ungar

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PEOPLE HAVE BEEN DEBATING THE NATURAL HUMAN DIET FOR THOUSANDS of years, often framed as a question of the morality of eating other animals. The lion has no choice, but we do. Take the ancient Greek philosopher Pythagoras, for example: "Oh, how wrong it is for flesh to be made from flesh!" The argument hasn't changed much for ethical vegetarians in 2,500 years, but today we also have Sarah Palin, who wrote in *Going Rogue: An American Life,* "If God had not intended for us to eat animals, how come He made them out of meat?" Have a look at Genesis 9:3—"Every moving thing that liveth shall be meat for you."

While humans don't have the teeth or claws of a mammal evolved to kill and eat other animals, that doesn't mean we aren't "supposed" to eat meat, though. Our early *Homo* ancestors invented weapons and cutting tools in lieu of sharp carnivorelike teeth. There is no explanation other than meat eating for the fossil animal bones riddled with stone tool cut marks at fossil sites. It also explains our simple guts, which look little like those evolved to process large quantities of fibrous plant foods.

But gluten isn't unnatural either. Despite the pervasive call to cut carbs, there is plenty of evidence that cereal grains were staples, at least for some, long before domestication. People at Ohalo II on the shore of the Sea of Galilee ate wheat and barley during the peak of the last ice age, more than 10,000 years before these grains were domesticated. Paleobotanists have even found starch granules trapped in the tartar on 40,000-year-old Neandertal teeth with the distinctive shapes of barley and other grains and the telltale damage that comes from cooking. There is nothing new about cereal consumption.

FOOD CHOICE IS AS MUCH ABOUT WHAT'S AVAILABLE TO BE EATEN AS IT IS ABOUT WHAT A SPECIES EVOLVED TO EAT.

This leads us to the so-called Paleolithic Diet. As a paleoanthropologist I'm often asked for my thoughts about it. I'm not really a fan—I like pizza and French fries and ice cream too much. Nevertheless, diet gurus have built a strong case for discordance between what we eat today and what our ancestors evolved to eat. The idea is that our diets have changed too quickly for our genes to keep up, and the result is said to be "metabolic syndrome," a cluster of conditions that include elevated blood pressure, high blood sugar level, obesity and abnormal cholesterol levels. It's a compelling argument. Think about what might happen if you put diesel in an automobile built for regular gasoline. The wrong fuel can wreak havoc on the system, whether you're filling a car or stuffing your face.

It makes sense, and it's no surprise that Paleolithic diets remain hugely popular. There are many variants on the general theme, but foods rich in protein and omega-3 fatty acids show up again and again. Grass-fed cow meat and fish are good, and carbohydrates should come from nonstarchy fresh fruits and vegetables. On the other hand, cereal grains, legumes, dairy, potatoes, and highly refined and processed foods are out. The idea is to eat like our Stone Age ancestors—you know, spinach salads with avocado, walnuts, diced turkey, and the like.

I am not a dietician and cannot speak with authority about the nutritional costs and benefits of Paleolithic diets, but I can comment on their evolutionary underpinnings. From the standpoint of paleoecology, the Paleolithic diet is a myth. Food choice is as much about what is available to be eaten as it is about what a species evolved to eat. And just as fruits ripen, leaves flush and flowers bloom predictably at different times of the year, foods available to our ancestors varied over deep time as the world changed around them from warm and wet to cool and dry and back again. Those changes are what drove our evolution.

Even if we could reconstruct the precise nutrient composition of foods eaten by a particular hominin species in the past (and we can't), the information would be meaningless for planning a menu based on our ancestral diet. Because our world was ever changing, so, too, was the diet of our ancestors. Focusing on a single point in our evolution would be futile. We're a work in progress. Hominins were spread over space, too, and those living in the forest by the river surely had a different diet from their cousins on the lakeshore or the open savanna.

What was the ancestral human diet? The question itself makes no sense. Consider some of the recent hunter-gatherers who have inspired Paleolithic diet enthusiasts. The Tikiġaġmiut of the north Alaskan coast lived almost entirely on the protein and fat of marine mammals and fish, whereas the Gwi San in Botswana's Central Kalahari took something like 70 percent of their calories from carbohydrate-rich, sugary melons and starchy roots. Traditional human foragers managed to earn a living from the larger community of life that surrounded them in a remarkable variety of habitats, from near-polar latitudes to the tropics. Few other mammalian species can make that claim, and there is little doubt that dietary versatility has been key to the success we've had.

Many paleoanthropologists today believe that increasing climate fluctuation through the Pleistocene sculpted our ancestors—whether their bodies or their wit, or both—for the dietary flexibility that has become a hallmark of humanity. The basic idea is that our ever changing world winnowed out the pickier eaters among us. Nature has made us a versatile species, which is why we can find something to satiate us on nearly all its myriad biospheric buffet tables. It's also why we have been able to change the game, transition from forager to farmer, and really begin to consume our planet. SA

Peter S. Ungar is Distinguished Professor and director of the Environmental Dynamics Program at the University of Arkansas. He is author of *Evolution's Bite: A Story of Teeth, Diet, and Human Origins* (Princeton University Press, 2017).

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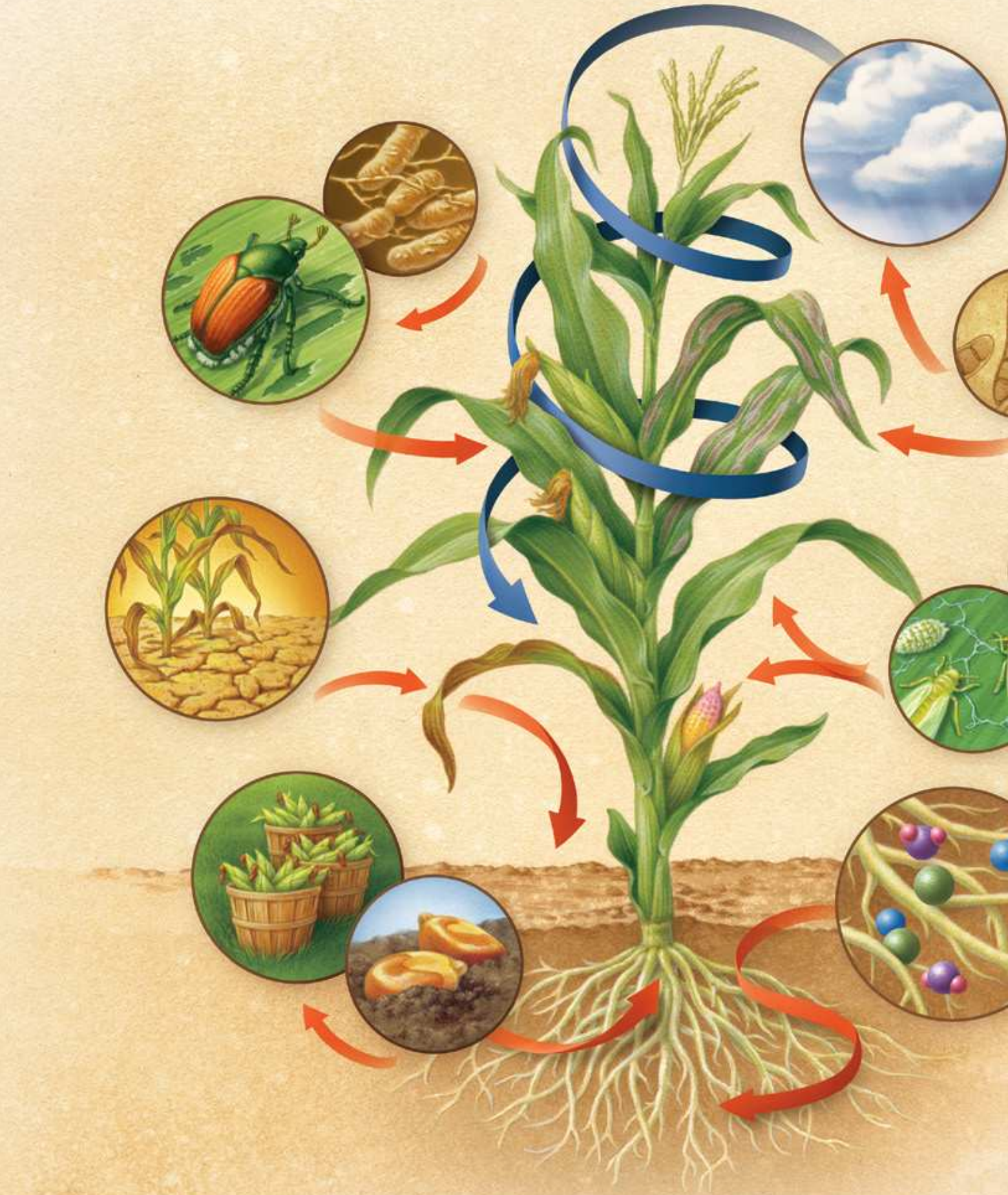

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BUILDING A BETTER HARVEST

Scientists are learning to manipulate the complex conversation that plants have with microbes, pests, nutrients and other elements of the phytobiome in hopes of averting a future famine

By Marla Broadfoot

Illustrations by Cherie Sinnen

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MERCEDES DIAZ TRAMPS INTO A MUDDY SOYBEAN FIELD AND RUNS her brightly manicured fingers through the limbs of dozens of knee-high plants. As she checks the stems, pods and leaves, she rattles off a list of possible maladies under her breath: pod borers, frogeye leaf spot, white mold. Diaz spots a tangle of mottled leaves and shouts, "SDS!"—signaling sudden death syndrome. She plucks one of the leaves and hands it to me. I turn the crinkly, palm-sized leaf over in my hand. Irregular holes riddle its surface, along with ugly brown spots tinged in yellow—the effects of a toxin produced by the SDS fungus that courses through the plant, robbing it of its pods and chewing up the leaves from the inside out. SDS is one of the top crop killers in the U.S. According to the United Soybean Board, it cost farmers more than 60 million bushels in lost yields in 2014. And yet Diaz could not be happier to see it in her field.

A plant pathologist, Diaz is one of a myriad of researchers hunting for new ways to protect crops from threats and to dramatically boost yields. In 2016 her team coated seeds with thousands of different microbes and planted them, along with control plots of untreated seeds, in half a million spots throughout the Midwest and South. Along the perimeter of these fields, the researchers deposited sentinel plots—sown with varieties susceptible to disease that act like the proverbial canary in the coal mine, warning of harms that might come to the rest of the crops. When Diaz finds SDS or some other blight in the sentinel plots and not in the test plots, it could be a sign that the microbes are working, helping to produce healthier, more abundant crops.

Yet on this rainy September day, Diaz finds that both the test plots and the control plots have escaped the sentinels' fate. The microbes did not make a difference—or did they? Even an improved yield as high as six bushels per acre (over an average of about 50 bushels per acre for soy) is nearly impossible to spot on sight. She will have to wait for the plants to be harvested and the data to be analyzed to find out if any of the microbes helped.

Crop research tends to be a slow-paced, hit-or-miss business, but scientists such as Diaz feel they are racing against the clock. If agriculture does not change radically over the next few decades, there may not be enough food to go around. The world's population is projected to increase from 7.5 billion to 9.7 billion people by 2050. To feed those additional mouths—and accommodate changing diets that include more meat—farmers will need to increase food production by about 70 per-

IN BRIEF

To meet the global need for food, scientists are finding ways to exploit the phytobiome—the complex web that links crops with microbial communities, soil, weather, animals and other environmental factors.

Among the most promising innovations are seeds coated with bacteria or fungi that can deter pests or otherwise promote growth. The first such products are already on the market.

Phytobiome-based interventions are likely to be less controversial than genetically modified seeds, but they do pose some potential risks. In any case, biotechnology alone cannot resolve world hunger.

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cent, according to the United Nations Food and Agriculture Organization (FAO). It is a tall order made taller by a number of worrisome trends. Global acreage of farmable land is shrinking as a result of urbanization and climate change, among other factors. Annual gains in yields for essential food crops have been plateauing, according to the FAO. Fertilizer use, for example, has reached a tipping point in which piling more chemicals onto fields will likely do more harm than good. Even genetically modified crops, at times both the devil and the darling of agriculture, have not lived up to their promise to supercharge food production.

"We need to stop looking for silver bullets," says Jan Leach, a plant pathologist at Colorado State University. "This is not a problem that any one of us can solve on our own, and it will require very diverse teams of people working together in ways that we've never worked before." Leach and other scientists are championing a more holistic approach, one that takes into account how all the components on a farm—the plants, soils, microbes, insects and climate, known collectively as the phytobiome—interact to determine crop yields. The concept harks back to the writings of 19th-century naturalists Alfred Russel Wallace and Charles Darwin, who presented nature as a vast, interconnected web where species constantly adapt to the changing environment around them.

WITH THE WORLD'S POPULATION PROJECTED TO EXPLODE FROM 7.5 BILLION TO 9.7 BILLION BY 2050, FARMERS WILL NEED TO INCREASE FOOD PRODUCTION BY 70 PERCENT.

Take Diaz's beloved soybeans. When an insect lands on a soybean leaf, the plant might respond by secreting volatile chemicals through its roots, which, in turn, alter the microbial makeup of the soil. These microbes could then switch on an array of genes in neighboring plants, putting them on high alert for a potential attack. Such critical plant defenses are sensitive, however, to various environmental factors and could, for example, be vulnerable to climate change. Pathogens have their own amazing tricks. Some can shoot themselves off the surface of a leaf like a cannonball, catching a ride on air currents from field to field, continent to continent. From the clouds, some strains of high-flying microbes can even influence the weather, summoning rain and hail to return them to the earth.

Scientists have suspected this complexity for centuries, but only recently have advances in technology enabled them to map these intricate interactions in the hope of developing more systematic, sustainable solutions for agriculture. Using gene-sequencing tools, they can now measure all the microbes in the soil, even the rare varieties or persnickety strains that are impossible to grow in the laboratory. They can track how these microbial communities shift in space and time, perhaps as the result of a surge in fertilizer or a drop in temperature. They can record the conversations that microbes, plants and other organisms have with one another and try to decipher how that chemical communication drives crop productivity and health.

One day a farmer may be able to ride a specially equipped tractor into a field and take a comprehensive census of its microbial residents, along with the more typical measurements of "precision agriculture"—such as the soil's moisture levels and nutrient content. Those factors could then be combined with data on previous crop yields, potential pests and pathogens, and projected weather patterns to predict which combination of seeds, nutrients, chemicals and microbes should give the highest yield.

The movement to make this vision a reality has only just begun. In 2016 a diverse band of scientists released an ambitious plan for transforming the future of agriculture, *Phytobiomes: A Roadmap for Research and Translation*. With the *Roadmap* came the creation of the *Phytobiomes* journal, an academic publication, and the Phytobiomes Alliance, an industry-academic collaboration that includes more than a dozen entities—newbies such as BioConsortia and Indigo and familiar names such as Diaz's employer, Monsanto. Over the past couple of years these companies have invested heavily to ramp up research and development, vying for their share of the global agricultural biologicals market, projected to reach $10 billion by 2020.

They see the ground below our feet—and its vast network of resident microorganisms—as vital to that effort. Soil-dwelling bacteria and fungi can help plants grow, cope with stress, bolster immune responses, and ward off pests and diseases. Farmers have known some of this since the late 1800s, when they began treating their pea and bean patches with the bacterium rhizobium, which adds nitrogen to the soil. Nowadays dozens of products based on the soil microbiome are on the market, with more on the way. Monsanto, in partnership with Denmark-based Novozymes, is betting big on microbe-laced seeds developed through the massive experiment that Diaz is part of. Other researchers are trying different tacks, such as altering the genome of crop plants in ways that would attract useful microbes or manipulating pest-plant communication so that crops can better detect and respond to a threat. Given the phytobiome's complexity, the possible avenues of influence are infinite. So are the dead ends. The challenge is to hit pay dirt in time to avert famine.

NOTES FROM UNDERGROUND

AN HOUR OUTSIDE OF ST. LOUIS, the cornfields look withered and pale in the mid-September sunlight. Stretches of soybeans resemble 1970s-style shag carpet dyed in shades of avocado green and harvest gold. I am traveling with Diaz and her colleagues to an unmarked site on the fringes of Stonington, Ill. As I step into a puddle, I grab my copy of the field map showing where thousands of microbe-laden seeds were sown. The microbes had been grown in vats of rich broth, coated on the seeds inside giant stainless-steel bowls and then kept frozen until planting time. Once the seeds sprout, these microbes spring to life, but what happens next is shaped by the multiple factors that make up the phytobiome.

I enter a maze of cornstalks behind Diaz, who shows me several sentinel ears covered in pink mold, swarming with tiny whiteflies. Plants lack a bona fide immune system, but they

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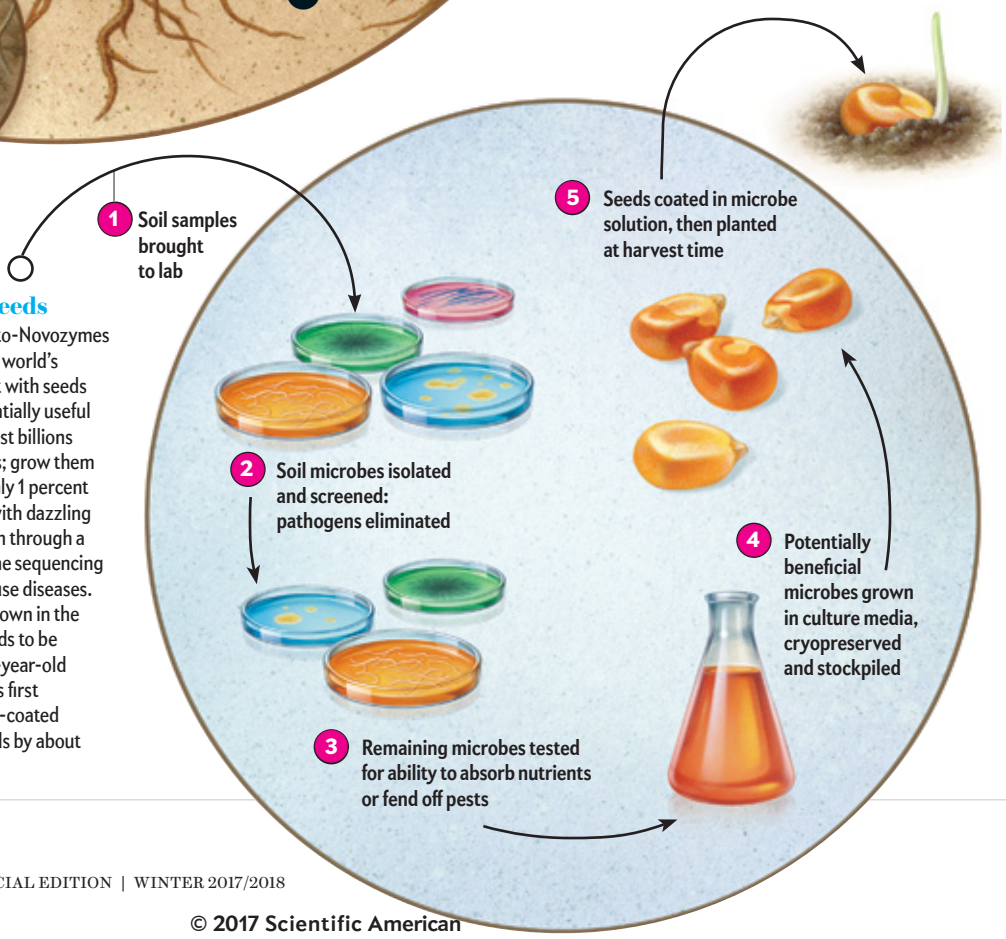
Hacking the Phytobiome

Crops (a) engage in a constant give-and-take with the living and inorganic elements of their environment, or phytobiome. This dialogue influences the plants' health. Bacteria, fungi and viruses (b) found on leaves, stems and roots and in the air and earth can provide a boost or a blight. The quality of soil (c) can alter how water, carbon and nutrients are cycled. Nutrients (d) such as nitrogen and phosphorus spur growth, but their overuse in chemical fertilizers degrades soil. Animals (e) such as rabbits and beetles are among the top crop destroyers; others, such as earthworms, can be useful. Weather (f) and a changing climate impact all elements of this ecosystem. The case studies here demonstrate two ways agricultural scientists are trying to shape the phytobiome to improve crop yields.

Case Study: Coated Seeds

The BioAg Alliance—a Monsanto-Novozymes partnership—is conducting the world's largest field-testing experiment with seeds that have been laced with potentially useful microbes. Its researchers harvest billions of soil microbes from U.S. farms; grow them in petri dishes, where the roughly 1 percent that survive produce colonies with dazzling shapes and colors; and run them through a battery of tests that include gene sequencing to eliminate those known to cause diseases. Promising microbes are then grown in the laboratory and coated onto seeds to be planted in test fields. The three-year-old project has already produced its first commercial product: a microbe-coated corn variety that increases yields by about three bushels per acre.


1 Soil samples brought to lab
2 Soil microbes isolated and screened: pathogens eliminated
3 Remaining microbes tested for ability to absorb nutrients or fend off pests
4 Potentially beneficial microbes grown in culture media, cryopreserved and stockpiled
5 Seeds coated in microbe solution, then planted at harvest time

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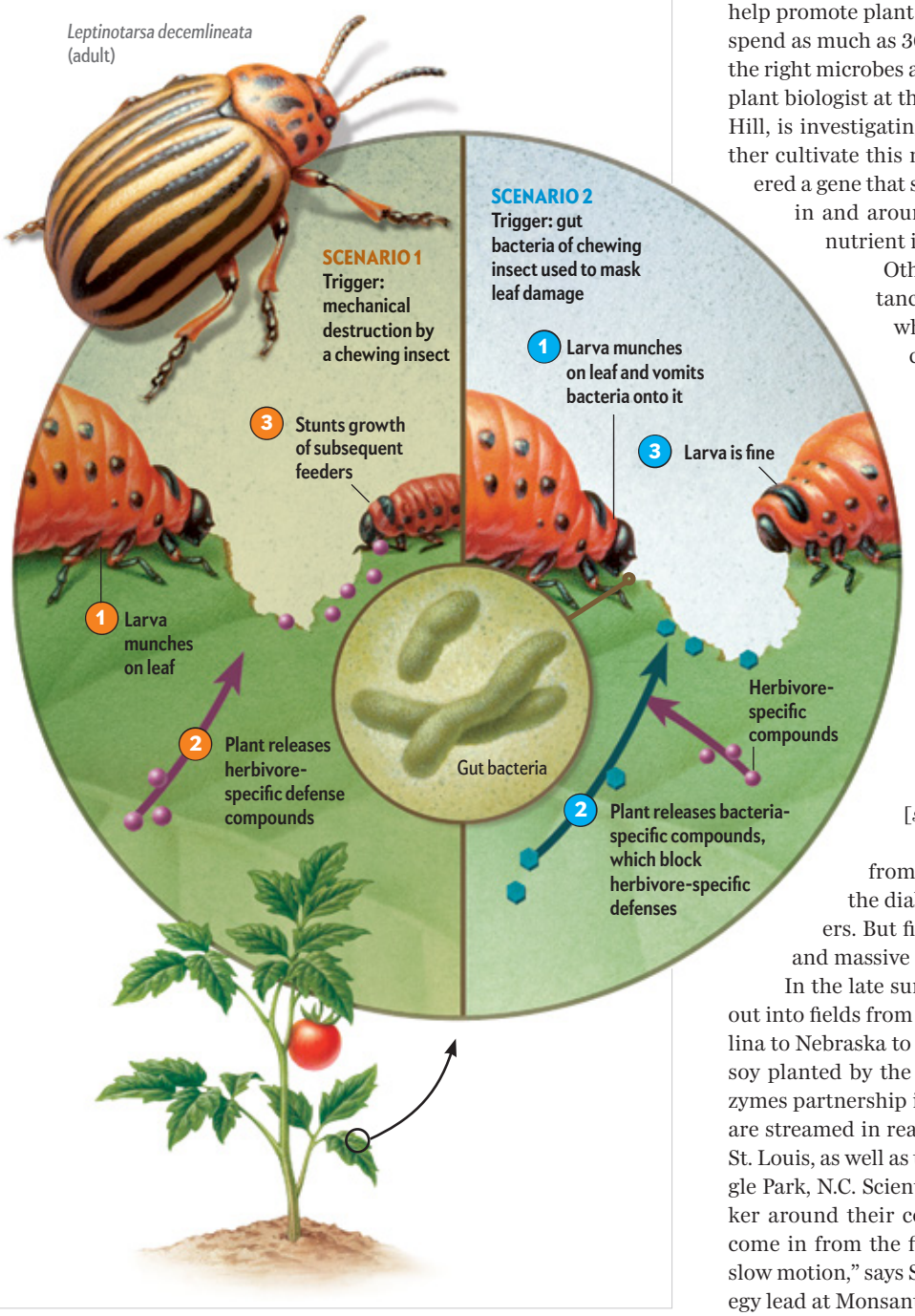
Case Study: Microbe/Herbivore/Plant Interaction

Plants lack a formal immune system, but they can detect and respond to assaults by bugs and bacteria. An attack by chewing insects can trigger plants to release compounds that interfere with the insects' digestion and growth (*scenario 1*). A bacterial blitz provokes the release of different, antimicrobial compounds. Some insects, such as Colorado potato beetle larvae, can trick their host by regurgitating gut bacteria onto leaves, leading the plant to issue the wrong defense and leaving the insects unharmed (*scenario 2*). New research is exploring ways to unmask this deception.


Leptinotarsa decemlineata (adult)
SCENARIO 1
Trigger: mechanical destruction by a chewing insect
1 Larva munches on leaf
2 Plant releases herbivore-specific defense compounds
3 Stunts growth of subsequent feeders
SCENARIO 2
Trigger: gut bacteria of chewing insect used to mask leaf damage
1 Larva munches on leaf and vomits bacteria onto it
2 Plant releases bacteria-specific compounds, which block herbivore-specific defenses
3 Larva is fine
Herbivore-specific compounds
Gut bacteria

have evolved a number of maneuvers to fend off insects. Some plants can thicken the walls of their cells so that intruders cannot get through, or they send toxic chemicals out to their roots or leaves to make them less palatable. Nicotine, caffeine and even the tannins that give red wine its astringent quality are all products of plant defenses.

Centuries of breeding and decades of genetic engineering have sought to enhance plant defenses and build other useful traits that increase crop yields. For example, more than half of the corn now grown in the U.S. contains a gene from an insect-killing bacterium called *Bacillus thuringiensis,* or Bt, that enables the corn to destroy beetle larvae. Now scientists are searching for other, phytobiome-related traits that could help promote plant health. They have discovered that plants spend as much as 30 percent of their energy trying to attract the right microbes and repel the wrong ones. Jeffery Dangl, a plant biologist at the University of North Carolina at Chapel Hill, is investigating ways to alter the plant genome to further cultivate this microbial entourage. He recently discovered a gene that shapes the communities of bacteria living in and around roots to soak up more phosphate—a nutrient in dwindling supply—from the soil.

Other phytobiome research focuses on resistance to bugs. Typically a plant can detect when pests are afoot by the presence of special chemicals called elicitors in the saliva of chewing insects. Gary Felton, an entomologist at Pennsylvania State University, and his colleagues discovered that some beetles and caterpillars can mask these telltale molecules by spitting up gut microbes onto the leaf, tricking the plant into reacting as if it were bathed in bacteria rather than ravaged by bugs. The misguided response to microbes actually disrupts the plant's ability to defend against insects. Recently Felton showed that feeding beetles a particular kind of bacteria skewed their microbiome enough so that they could no longer fool the plant [*see box at left*].

The next green revolution could spring from any or all of these methods of shaping the dialogue among plants, pests and soil dwellers. But first, there are experimental crops to tend and massive numbers to crunch.

In the late summer of 2015 a fleet of machines fanned out into fields from Louisiana to Minnesota and North Carolina to Nebraska to harvest each of the test plots of corn and soy planted by the BioAg Alliance, as the Monsanto-Novozymes partnership is known. Data from the burly harvesters are streamed in real time back to Monsanto's data center in St. Louis, as well as to Novozymes's facility in Research Triangle Park, N.C. Scientists in both locations are known to hunker around their computer screens to watch the numbers come in from the fields. "It's like watching a horse race in slow motion," says Scott Schaecher, biotechnology data strategy lead at Monsanto.

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They have found it best not to put too much stock in the early results. The raw data can be deceptive because they do not take into account factors that might give a particular microbe a head start or make it fall behind. The soil microbiome can vary from plot to plot, even across a field. Weather can wreak havoc: seed coatings can be washed off by early rains, and one year the alliance lost thousands of plots to Hurricane Joaquin. In addition to half a million yield points, the team collects 50 different measurements on each of its soil samples. Add in other phytobiome data, and you end up with terabytes of information, what Schaecher calls either "a statistician's carnival or nightmare."

On his office computer, Schaecher pulls up a U.S. map decorated in red and green dots like a Christmas tree: green for the microbes that boosted yield, red for those that lowered it. They represent 2016 results from five corn fields. He and his team can break down the data according to soil and environmental characteristics, weather, and insect and disease pressure. They can zoom in on the locations with high levels of Diaz's SDS to see if they can identify any microbes that excelled under those conditions.

EVEN IF THERE WERE A BROADER SHARING OF DATA AMONG CROP SCIENTISTS IN PRIVATE INDUSTRY, ACADEMIA AND GOVERNMENT, WORLD HUNGER IS NOT LIKELY TO BE SOLVED BY BIOTECH INNOVATION ALONE. IT WILL ALSO TAKE POLITICAL WILL.

The team uses a "field first" strategy, which means it skips the typical greenhouse experiments and tests its candidates directly in the field. As a result, the researchers have no idea which, if any, microbes will give an advantage. In 2014, the first year of the field trial, they planted seeds coated with 500 different strains. Ninety percent of the microbes failed. In 2015 they put 2,000 microbes into the race, including the winners from the first year. After that trial, only a handful of the original contenders remained, along with a couple hundred of the newbies. In 2016 the scientists planted another 2,000 strains, made up of the top performers and a batch of new recruits. Three years into the experiment, only a single microbe from the initial round—plus hundreds from later rounds—remained in contention. The team is not looking for one-hit wonders—it wants Triple Crown winners that perform consistently, year after year, on multiple fields.

RISKY BUSINESS?

WORKING WITH ALL-NATURAL MICROBES—taken from farmland, grown in the lab and then returned to the farm—might seem like a harmless proposition, free of the kind of controversies associated with genetically modified organisms (GMOs). Nevertheless, it raises a number of concerns. Messing with the microbial milieu could affect the flavor of a crop, much as soil composition influences the taste of wine. A yield-boosting bacterium might possess pathogenic properties that prove harmful to human health. Long-term applications of plant probiotics could change the natural dynamics of soil, fueling the proliferation of some microorganisms while driving others to extinction. There is also a risk that seed coatings, like many agents applied to a field, could slough off one crop and contaminate another.

Schaecher says the BioAg Alliance works hard to avoid such problems. It puts its microbial strains through a battery of tests before introducing them into the field. It sequences each genome to make sure the microbe bears no resemblance to known human pathogens and runs other tests to assess if it might be toxic to the environment or spread to another crop. He and his team consult regularly with the U.S. Department of Agriculture, which decides whether a permit is required before a particular microbial species can undergo field-testing. Organisms with benign duties such as fixing nitrogen or solubilizing phosphate typically get a pass. Those with more dangerous jobs such as killing off other bacteria or fungi require more paperwork.

Among agricultural researchers, the bigger concern is not that newly introduced species will take over or spread to other crops but rather that they will not stick around long enough to do much of anything, says Gwyn Beattie, a plant pathologist at Iowa State University and one of the authors of the *Phytobiomes Roadmap*. A spoonful of soil contains about 50 billion microbes, a mix of up to 10,000 different species. Researchers can add millions of one strain to the soil and not make a dent. "If you throw one person [at a time] into New York City, the vast majority of people you throw in there do not change New York City," Beattie says. "It is like that in a microbial community. Introducing organisms rarely has an impact at all, and that's actually the biggest frustration." (A similar challenge has mired the human probiotics industry, which aims to enhance the multitrillion-member microbial community in the human gut. Its powders, pills and potables have been promoted for treating ailments ranging from diarrhea to depression, but few studies show any measurable effect.)

Still, Monsanto's activities have worried large segments of the public, which have accused the company of endangering human health, trampling the rights of farmers and monopolizing the food supply. Most of this ire arose in the mid-1990s, when the agricultural giant launched a line of GMO crops. Since then, two opposing narratives have emerged: one in which the company develops seeds that double yields and heroically overcome food shortages; the other in which its products defile farmlands and cause cancer. In 2016 the National Academy of Sciences completed what may be the most thorough examination of GMOs to date and found neither to be true. Its report concluded that genetically modified crops were just as safe to eat as conventional crops but that "there is no evidence" that GMOs have boosted progress on yields.

The primary benefit from genetically modified soybean, cotton and maize, the report suggested, was "favorable economic outcomes for producers who have adopted these crops." When I asked about the academy's lackluster findings, a Monsanto representative admitted that the company had shifted its sales pitch from feeding the world to helping farmers get the best possible yields at the lowest cost. Monsanto's sales totaled $13.5

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billion in 2016, nearly $10 billion of which came from seeds, many of them genetically enhanced. The advances of the past two decades have saved money for farmers and made money for industry, but the need for more food remains urgent.

TOMORROW'S HARVEST

THE SEEDS PLANTED on American farms today are not your grandfather's seeds. They typically carry as many as 14 different genetically engineered traits, piled on top of one another. These "stacks," as they are called in industry speak, are often accompanied by a host of other potentially yield-boosting products, including fertilizers, herbicides and, more recently, biologicals such as the BioAg Alliance's microbial seed coatings. Yet there is still a lot we do not know about what goes into a healthy crop—and scientists in academia and the government, as well as big agriculture, are all trying to figure it out.

Even with advances in sequencing technology, scientists have identified only 1 percent of the microbial species in soil. The murky nature of soil has made visualizing what is happening underground difficult. Scientists have had to resort to destructive end-point studies—shoveling up scoops of soil and taking a rough survey of its microbial constituents, like a giant running its hands across the earth to capture a sample of humankind. That approach might indicate which people are there but not what they were doing or how they were interacting before their world was turned upside down.

A few years ago a team in Scotland concocted a see-through artificial soil that allows researchers to spy on the microbial communities associated with plant roots. Elizabeth Shank, a microbiologist at Chapel Hill, has been using this transparent soil to study the microbes' signals. These chemical messages range from lethal—70 percent of antibiotics are derived from metabolites that microbes use to off one another—to productive—some microbes use them to announce they are gathering to form a biofilm so that they can stick onto the surface of roots. In November 2016 Shank presented her work at a symposium on phytobiomes in Santa Fe, N.M. She explained that by painting different microbial metabolites with fluorescent markers, she can watch messages travel between communities as they react to events such as the planting of a seed, a rise in temperatures or an invasion by pathogens.

Her innovation may yield big payoffs. Or not. Many academics such as Shank are licensing their discoveries to businesses or launching their own start-ups. The commercial ecosystem is thrumming with new entities, collaborations and mergers, including September 2016's $66-billion purchase of Monsanto by Bayer. The U.S. government has also gotten into the game. The 2014 "farm bill" allotted $200 million to establish the Foundation for Food and Agriculture Research (FFAR) to encourage academic-industry partnerships. In July 2016 FFAR convened a group of experts to brainstorm about how to reap the most benefits from the phytobiome.

Kellye Eversole, executive director of the Phytobiomes Alliance, says that although academia, government and industry might share similar goals, their methods are sometimes at odds. Because companies are beholden to their investors, they can have a short-term, profit-driven mentality. "Not having fundamental research and building that long-term pipeline can hurt us," she says. On the other hand, industry has resources the botany professors can only dream of: A few days after the FFAR event, Monsanto's Schaecher made a presentation at the American Phytopathological Society meeting, a yearly powwow of more than 1,500 plant pathologists. When he pulled up the map of the BioAg Alliance's field trials, Linda Kinkel, a plant pathologist at the University of Minnesota, nearly fell out of her chair. "If they're truly collecting data on 500,000 soil microbiomes, that's more than all the rest of us put together," Kinkel says. And she worries, "How much science is in there that we'll never see?"

Leveraging the phytobiome to improve crops will require a thorough integration of information from different sources and disciplines, but many of the parties involved are not forthcoming. Farmers are hesitant to give others access to the data they gather in their fields, citing privacy concerns. The BioAg Alliance occasionally feeds bits and pieces to academic collaborators, but Schaecher says it cannot share all its data because Monsanto and Novozymes have to "protect their competitive advantage." In 2017 the alliance launched its first product, a microbial seed coating based on a fungus found in cornfield soil that increased yields by an average of three bushels per acre in field tests. Projections suggest the product could be used to boost crop yields on up to 90 million acres of farmland globally.

It is a start but a long way from meeting the needs of an increasingly burdened planet. Even if there were a broader sharing of data among crop scientists, world hunger will not likely be solved through biotech innovation alone. That entails addressing not only the food supply but also food waste, distribution challenges, war, political strife, income inequality and climate change. Fred Gould, an entomologist at North Carolina State University, who led the National Academy of Sciences review of GMOs, cautions that even if scientists could somehow double food production, it might not be the right thing to do if it leaves the soil ravaged and unable to support future crops. He also warns that solutions have to work on the ground. "You can have all of this knowledge, but it is so environment-dependent, you are going to have to manipulate [the phytobiome] for each farm," Gould says. "When the rubber meets the road, some of these ideas are hard to put into practice." In the end, hacking the phytobiome will likely be just part of the next agricultural revolution. It will also take political will and a lot of luck. After all, 2050 is a mere 32 annual cropping cycles away. SA

Marla Broadfoot is a freelance science journalist and contributing editor at *American Scientist*. She is based in Wendell, N.C., and has a Ph.D. in genetics and molecular biology.

MORE TO EXPLORE

How Microbes Can Help Feed the World. Ann Reid and Shannon E. Greene. American Academy of Microbiology Colloquium, August 2013. www.asm.org/images/stories/documents/FeedTheWorld.pdf

Herbivore Exploits Orally Secreted Bacteria to Suppress Plant Defenses. Seung Ho Chung et al. in *Proceedings of the National Academy of Sciences USA*, Vol. 110, No. 39, pages 15,728–15,733; September 24, 2013.

Phytobiomes: A Roadmap for Research and Translation. American Phytopathological Society, 2016. www.phytobiomes.org/Roadmap/Pages/default.aspx

Microbes Added to Seeds Could Boost Crop Production. Marla Broadfoot in ScientificAmerican.com. Published online January 6, 2016. www.scientificamerican.com/article/microbes-added-to-seeds-could-boost-crop-production

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Paleo Diets, GMOs and Food Taboos

What do we mean by "natural"?

By Michael Shermer

IN 1980 I SUBJECTED MYSELF to a week-long cleansing diet of water, cayenne pepper, lemon and honey, topped off with a 150-mile bicycle ride that left me puking on the side of the road. Neither this nor any of the other fad diets I tried in my bike-racing days to enhance performance seemed to work as well as the "see-food" diet one of my fellow cyclists was on: you see it, you eat it.

In its essence, the see-food diet was the first so-called Paleo diet, not today's popular fad, premised on the false idea that there is a single set of natural foods—and a correct ratio of them—that our Paleolithic ancestors ate. Anthropologists have documented a wide variety of foods consumed by traditional peoples, from the Masai diet of mostly meat, milk and blood to New Guineans' fare of yams, taro and sago. As for food ratios, according to a 2000 study entitled "Plant-Animal Subsistence Ratios and Macronutrient Energy Estimations in Worldwide Hunter-Gatherer Diets," published in the *American Journal of Clinical Nutrition,* the range for carbohydrates is 22 to 40 percent, for protein 19 to 56 percent, and for fat 23 to 58 percent.

And what constitutes "natural" anyway? Humans have been genetically modifying foods through selective breeding for more than 10,000 years. Were it not for these original genetically modified organisms—and today's more engineered GMOs designed for resistance to pathogens and herbicides and for better nutrient profiles—the planet could sustain only a tiny fraction of its current population. Golden rice, for example, was modified to enhance vitamin A levels, in part, to help Third World children with nutritional deficiencies that have caused millions to go blind. As for health and safety concerns, according to *A Decade of EU-Funded GMO Research,* a 2010 report published by the European Commission: "The main conclusion to be drawn from the efforts of more than 130 research projects, covering a period of more than 25 years of research, and involving more than 500 independent research groups, is that biotechnology, and in particular GMOs, are not per se more risky than e.g. conventional plant breeding technologies."

So why are so many people in a near moral panic over GMOs? One explanation may be found in University of California, Los Angeles, anthropologist Alan Fiske's four-factor relational model theory of how people and objects interact: (1) communal sharing (equality among people); (2) authority ranking (between superiors and subordinates); (3) equality matching (one-to-one exchange); and (4) market pricing (from barter to money). Our Paleolithic ancestors lived in egalitarian bands in which food was mostly shared equally among members (communal sharing). As these bands and tribes coalesced into chiefdoms and states, unequal distribution of food and other resources became common (authority ranking) until the system shifted to market pricing.

Violations of these relations help to show how GMOs have come to be treated more like moral categories than biological entities. Roommates, for example, are expected to eat only their own food or to replace one another's consumed items (equality matching), whereas spouses share without keeping tabs (communal sharing). If you invite friends to dinner, it would be disconcerting if they offered to pay for the meal, but if you dine at a restaurant, you are required to pay the bill and not summon the owner to your home for a comparable cuisine. All four relational models are grounded in our natural desire for fairness and reciprocity, and when there is a perceived violation, it creates a sense of injustice.

Given the importance of food for survival and flourishing, I suspect GMOs—especially in light of their association with large corporations such as Monsanto that operate on the market-pricing model—feel like an infringement of communal sharing and equality matching. Moreover, the elevation of "natural foods" to near-mythic status, coupled with the taboo many genetic-modification technologies are burdened with—remember when in vitro fertilization was considered unnatural?—makes GMOs feel like a desecration. It need not be so. GMOs are scientifically sound, nutritionally valuable and morally noble in helping humanity during a period of rising population. Until then, eat, drink and be merry. SA

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His latest book is *Heavens on Earth* (Henry Holt, 2018). Follow him on Twitter @michaelshermer

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6

evolution vs. creationism

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(evŏliū·ʃən)

More than a century and a half after the publication of Charles Darwin's groundbreaking book *On the Origin of Species,* the theory of evolution through natural selection has been tested and confirmed innumerable times. It is a cornerstone of modern biology. As the evolutionary biologist Theodosius Dobzhansky observed, "nothing in biology makes sense except in the light of evolution." And yet the teaching of evolution in schools continues to come under attack from creationists. Their arguments do not stand up to scrutiny, however (*page 94*). Moreover, the teaching of evolution is constitutionally protected in the U.S. Nevertheless, American science teachers still face considerable pressure to compromise their presentations (*page 104*) on this fundamental concept. What is the best way to oppose religiously motivated threats to scientific thinking? Perhaps not surprisingly that, too, is a matter of debate (*page 108*).

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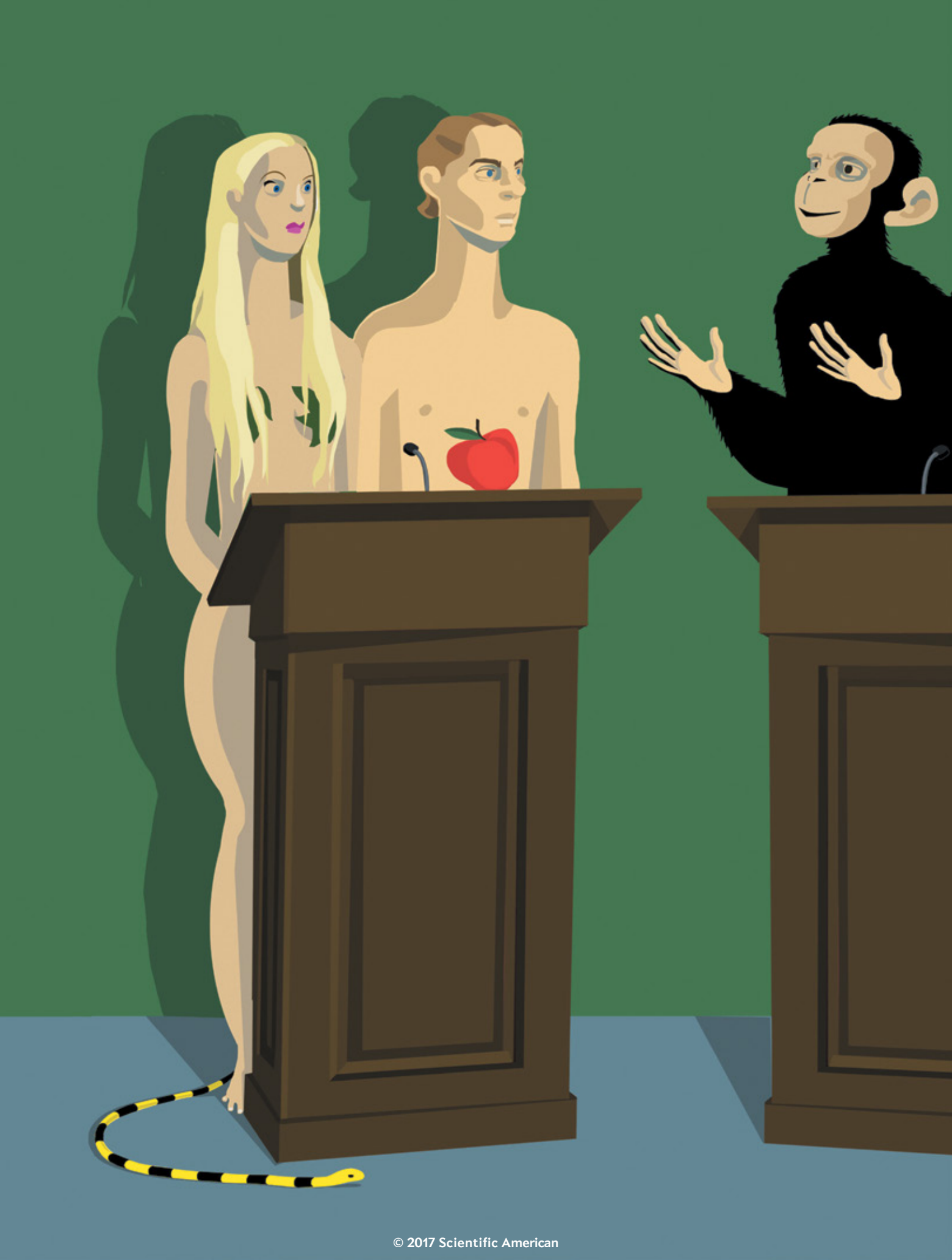

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15

ANSWERS TO CREATIONIST NONSENSE

OPPONENTS OF EVOLUTION WANT TO MAKE A PLACE FOR CREATIONISM BY TEARING DOWN REAL SCIENCE, BUT THEIR ARGUMENTS DON'T HOLD UP

By John Rennie

Illustration by Alison Seiffer

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WHEN CHARLES DARWIN INTRODUCED THE THEORY of evolution through natural selection 158 years ago, the scientists of the day argued over it fiercely, but the massing evidence from paleontology, genetics, zoology, molecular biology and other fields gradually established evolution's truth beyond reasonable doubt. Today that battle has been won everywhere—except in the public imagination. Embarrassingly, in the 21st century, in the most scientifically advanced nation the world has ever known, creationists can still persuade politicians, judges and ordinary citizens that evolution is a flawed, poorly supported fantasy. They lobby for creationist ideas such as "intelligent design" to be taught as alternatives to evolution in science classrooms. When this article first went to press in 2002, the Ohio Board of Education was debating whether to mandate such a change. Prominent antievolutionists of the day, such as Philip E. Johnson, a law professor at the University of California, Berkeley, and author of *Darwin on Trial,* admitted that they intended for intelligent-design theory to serve as a "wedge" for reopening science classrooms to discussions of God.

The good news is that in 2005 the landmark legal case *Kitzmiller v. Dover* in Harrisburg, Pa., set binding precedent that the teaching of intelligent design in U.S. public schools is unconstitutional because the idea is fundamentally religious, not scientific. The bad news is that in response, creationists have reinvented their movement and pressed on. When they lost the ability to claim that creationist ideas are valid science, they switched to arguing that they were only supporting "academic freedom." Worse, to further obscure the religious roots of their resistance, they now push for "critical analysis" of climate change, cloning research and other scientific endeavors that they paint as culturally oppressive.

Consequently, besieged teachers and others are still likely to find themselves on the spot to defend evolution and refute creationism, by whatever name. Creationists' arguments are typically specious and based on misunderstandings of (or outright lies about) evolution. Nevertheless, even if their objections are flimsy, the number and diversity of the objections can put even well-informed people at a disadvantage. The following list recaps and rebuts some of the most common "scientific" arguments raised against evolution. It also directs readers to further sources for information and explains why creation science has no place in the classroom. These answers by themselves probably will not change the minds of those set against evolution. But they may help inform those who are genuinely open to argument, and they can aid anyone who wants to engage constructively in this important struggle for the scientific integrity of our civilization.

IN BRIEF

Despite definitive legal cases that have established the unconstitutionality of teaching intelligent design or creationist ideology in science class, the theory of evolution remains consistently under attack.

Creationist arguments are notoriously errant or based on a misunderstanding of evolutionary science and evidence.

Hundreds of studies verify the facts of evolution, at both the microevolutionary and macroevolutionary scale—from the origin of new traits and new species to the underpinnings of the complexity we see in life and the statistical probability of such complexity arising.

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GALÁPAGOS FINCHES show adaptive beak shapes.

1. Evolution is only a theory. It is not a fact or a scientific law.

Many people learned in elementary school that a theory falls in the middle of a hierarchy of certainty—above a mere hypothesis but below a law. Scientists do not use the terms that way, however. According to the National Academy of Sciences (NAS), a scientific theory is "a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses." No amount of validation changes a theory into a law, which is a descriptive generalization about nature. So when scientists talk about the theory of evolution—or the atomic theory or the theory of relativity, for that matter—they are not expressing reservations about its truth.

In addition to the *theory* of evolution, meaning the idea of descent with modification, one may also speak of the *fact* of evolution. The NAS defines a fact as "an observation that has been repeatedly confirmed and for all practical purposes is accepted as 'true.'" The fossil record and abundant other evidence testify that organisms have evolved through time. Although no one observed those transformations, the indirect evidence is clear, unambiguous and compelling.

ACCEPTANCE OF EVOLUTION AS A FACTUAL OCCURRENCE AND A GUIDING PRINCIPLE IS UNIVERSAL IN BIOLOGY.

All sciences frequently rely on indirect evidence. Physicists cannot see subatomic particles directly, for instance, so they verify their existence by watching for telltale tracks that the particles leave in cloud chambers. The absence of direct observation does not make physicists' conclusions less certain.

2. Natural selection is based on circular reasoning: the fittest are those who survive, and those who survive are deemed fittest.

"Survival of the fittest" is a conversational way to describe natural selection, but a more technical description speaks of differential rates of survival and reproduction. That is, rather than labeling species as more or less fit, one can describe how many offspring they are likely to leave under given circumstances. Drop a fast-breeding pair of small-beaked finches and a slower-breeding pair of large-beaked finches onto an island full of food seeds. Within a few generations the fast breeders may control more of the food resources. Yet if large beaks more easily crush seeds, the advantage may tip to the slow breeders. In pioneering studies of finches on the Galápagos Islands, Peter Grant and Rosemary Grant of Princeton University observed these kinds of population shifts in the wild.

The key is that adaptive fitness can be defined without reference to survival: large beaks are better adapted for crushing seeds, irrespective of whether that trait has survival value under the circumstances.

3. Evolution is unscientific because it is not testable or falsifiable. It makes claims about events that were not observed and can never be re-created.

This blanket dismissal of evolution ignores important distinctions that divide the field into at least two broad areas: microevolution and macroevolution. Microevolution looks at changes within species over time—changes that may be preludes to speciation, the origin of new species. Macroevolution studies how taxonomic groups above the level of species change. Its evidence draws frequently from the fossil record and DNA comparisons to reconstruct how various organisms may be related.

These days even most creationists acknowledge that microevolution has been upheld by tests in the laboratory (as in studies of cells, plants and fruit flies) and in the field (as in the Grants' studies of evolving beak shapes among Galápagos finches). Natural selection and other mechanisms—such as chromosomal changes, symbiosis and hybridization—can drive profound changes in populations over time.

The historical nature of macroevolutionary study involves inference from fossils and DNA rather than direct observation. Yet in the historical sciences (which include astronomy, geology and archaeology, as well as evolutionary biology), hypotheses can still be tested by checking whether they accord with physical evidence and whether they lead to verifiable predictions about future discoveries. For instance, evolution implies that between the earliest known ancestors of humans (roughly five million years old) and the appearance of anatomically modern humans (about 200,000 years ago), one should find a succession of hominin creatures with features progressively less apelike and more modern, which is indeed what the fossil record shows. But one should not—and does not—find modern human fossils embedded in strata from the Jurassic period (65 million years ago). Evolutionary biology routinely makes predictions far more refined and precise than this, and researchers test them constantly.

Evolution could be disproved in other ways, too. If we could document the spontaneous generation of just one complex lifeform from inanimate matter, then at least a few creatures seen in the fossil record might have originated this way. If superintelligent aliens appeared and claimed credit for creating life

PATRICIA J. WYNNE

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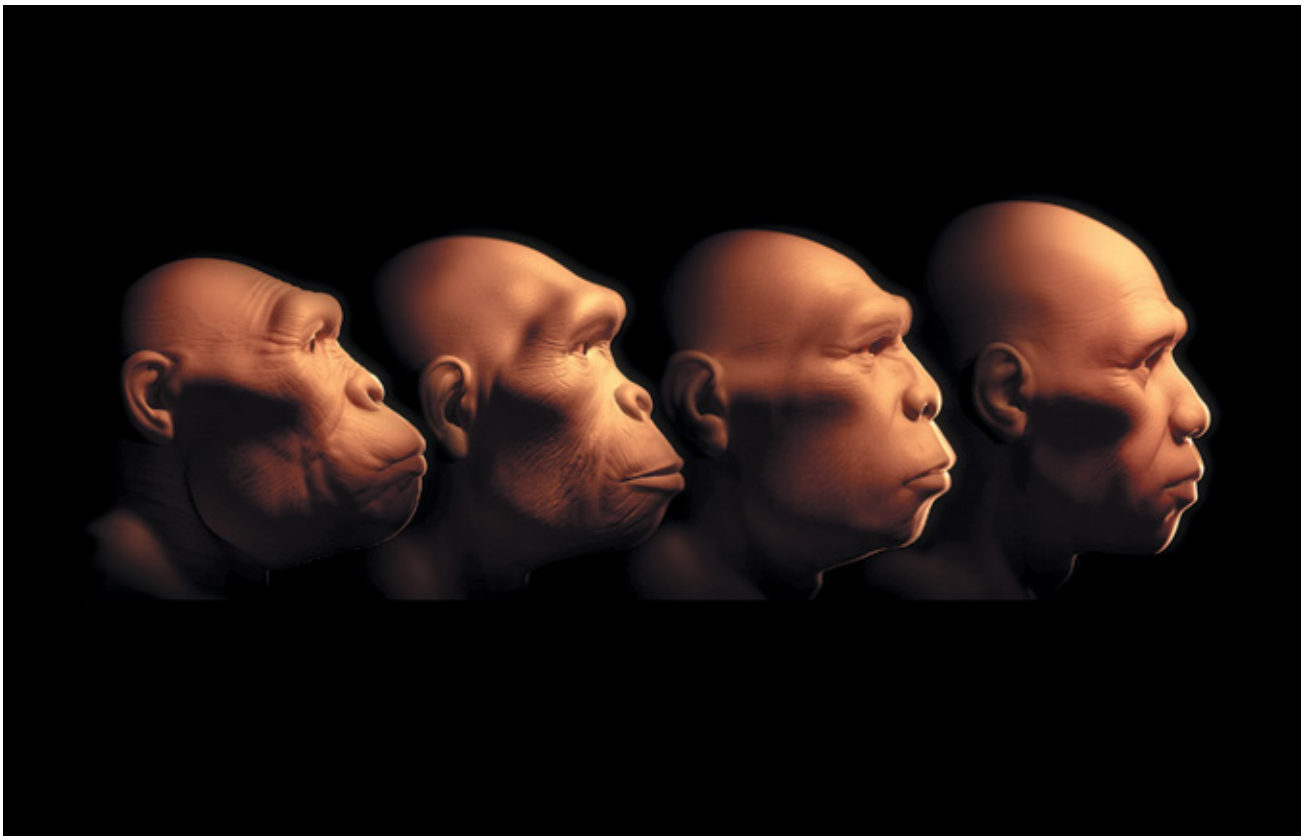

NEW SPECIES evolve by diverging away from established ones and acquire sufficient differences to remain forever distinct.

on Earth (or even particular species), the purely evolutionary explanation would be cast in doubt. But no one has yet produced such evidence.

It should be noted that the idea of falsifiability as the defining characteristic of science originated with philosopher Karl Popper in the 1930s. More recent elaborations on his thinking have expanded the narrowest interpretation of his principle precisely because it would eliminate too many branches of clearly scientific endeavor.

4. Increasingly, scientists doubt the truth of evolution.

No evidence suggests that evolution is losing adherents. Pick up any issue of a peer-reviewed biological journal, and you will find articles that support and extend evolutionary studies or that embrace evolution as a fundamental concept.

Conversely, serious scientific publications disputing evolution are all but nonexistent. In the mid-1990s George W. Gilchrist, then at the University of Washington, surveyed thousands of journals in the primary literature, seeking articles on intelligent design or creation science. Among those hundreds of thousands of scientific reports, he found none. Surveys done independently by Barbara Forrest of Southeastern Louisiana University and Lawrence M. Krauss, now at Arizona State University, were similarly fruitless.

Creationists retort that a closed-minded scientific community rejects their evidence. Yet according to the editors of *Nature, Science* and other leading journals, few antievolution manuscripts are even submitted. Some antievolution authors have published papers in serious journals. Those papers, however, rarely attack evolution directly or advance creationist arguments; at best, they identify certain evolutionary problems as unsolved and difficult (which no one disputes). In short, creationists are not giving the scientific world good reason to take them seriously.

5. The disagreements among even evolutionary biologists show how little solid science supports evolution.

Evolutionary biologists passionately debate diverse topics: how speciation happens, the rates of evolutionary change, the ancestral relationships of birds and dinosaurs, whether Neandertals were a species apart from modern humans, and much more. These disputes are like those found in all other branches of science. Acceptance of evolution as a factual occurrence and a guiding principle is nonetheless universal in biology.

Unfortunately, dishonest creationists have shown a willingness to take scientists' comments out of context to exaggerate and distort the disagreements. Anyone acquainted with the works of paleontologist Stephen Jay Gould of Harvard University knows that in addition to co-authoring the punctuated-equilibrium model, Gould was one of the most eloquent defenders and articulators of evolution. (Punctuated equilibrium explains patterns in the fossil record by suggesting that most evolutionary changes occur within geologically brief intervals—which may nonetheless amount to hundreds of generations.) Yet creationists delight in dissecting out phrases from Gould's

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FOSSIL RECORD shows a succession of hominins, with features becoming progressively less apelike and more modern.

voluminous prose to make him sound as though he had doubted evolution, and they present punctuated equilibrium as though it allows new species to materialize overnight or birds to be born from reptile eggs.

When confronted with a quotation from a scientific authority that seems to question evolution, insist on seeing the statement in context. Almost invariably, the attack on evolution will prove illusory.

6. If humans descended from monkeys, why are there still monkeys?

This surprisingly common argument reflects several levels of ignorance about evolution. The first mistake is that evolution does not teach that humans descended from monkeys; it states that both have a common ancestor.

The deeper error is that this objection is tantamount to asking, "If children descended from adults, why are there still adults?" New species evolve by splintering off from established ones, when populations of organisms become isolated from the main branch of their family and acquire sufficient differences to remain forever distinct. The parent species may survive indefinitely thereafter, or it may become extinct.

7. Evolution cannot explain how life first appeared on Earth.

The origin of life remains very much a mystery, but biochemists have learned about how primitive nucleic acids, amino acids and other building blocks of life could have formed and organized themselves into self-replicating, self-sustaining units, laying the foundation for cellular biochemistry. Astrochemical analyses hint that quantities of these compounds might have originated in space and fallen to Earth in comets, a scenario that may solve the problem of how those constituents arose under the conditions that prevailed when our planet was young.

Creationists sometimes try to invalidate all of evolution by pointing to science's current inability to explain the origin of life. But even if life on Earth turned out to have a nonevolutionary origin (for instance, if aliens introduced the first cells billions of years ago), evolution since then would be robustly confirmed by countless microevolutionary and macroevolutionary studies.

8. Mathematically, it is inconceivable that anything as complex as a protein, let alone a living cell or a human, could spring up by chance.

Chance plays a part in evolution (for example, in the random mutations that can give rise to new traits), but evolution does not depend on chance to create organisms, proteins or other entities. Quite the opposite: natural selection, the principal known mechanism of evolution, harnesses nonrandom change by preserving "desirable" (adaptive) features and eliminating "undesirable" (nonadaptive) ones. As long as the forces of selection stay constant, natural selection can push evolution in one direction and produce sophisticated structures in surprisingly short times.

As an analogy, consider the 13-letter sequence "TOBEORNOT-

E. R. DEGGINGER *Science Source*

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Misleading Semantics of Creationism

Only methodological naturalism can determine how all life came to be

"Creation science" is a contradiction in terms. A central tenet of modern science is methodological naturalism—it seeks to explain the universe purely in terms of observed or testable natural mechanisms. Thus, physics describes the atomic nucleus with specific concepts governing matter and energy, and it tests those descriptions experimentally. Physicists introduce new particles, such as quarks, to flesh out their theories only when data show that the previous descriptions cannot adequately explain observed phenomena. The new particles do not have arbitrary properties, moreover—their definitions are tightly constrained, because the new particles must fit within the existing framework of physics.

In contrast, intelligent-design theorists invoke shadowy entities that conveniently have whatever unconstrained abilities are needed to solve the mystery at hand. Rather than expanding scientific inquiry, such answers shut it down. (How does one disprove the existence of omnipotent intelligences?)

Intelligent design offers few answers. For instance, when and how did a designing intelligence intervene in life's history? By creating the first DNA? The first cell? The first human? Was every species designed, or just a few early ones? Proponents of intelligent-design theory frequently decline to be pinned down on these points. They do not even make real attempts to reconcile their disparate ideas about intelligent design. Instead they pursue argument by exclusion—that is, they belittle evolutionary explanations as farfetched or incomplete and then imply that only design-based alternatives remain.

Logically, this is misleading: even if one naturalistic explanation is flawed, it does not mean that all are. Moreover, it does not make one intelligent-design theory more reasonable than another. Listeners are essentially left to fill in the blanks for themselves, and some will undoubtedly do so by substituting their religious beliefs for scientific ideas.

Time and again, science has shown that methodological naturalism can push back ignorance, finding increasingly detailed and informative answers to mysteries that once seemed impenetrable: the nature of light, the causes of disease, how the brain works. Evolution is doing the same with the riddle of how the living world took shape. Creationism, by any name, adds nothing of intellectual value to the effort. —*J.R.*

TOBE." A million hypothetical monkeys, each typing out one phrase a second on a keyboard, could take as long as 78,800 years to find it among the 2613 sequences of that length. But in the 1980s Richard Hardison, then at Glendale College, wrote a computer program that generated phrases randomly while preserving the positions of individual letters that happened to be correctly placed (in effect, selecting for phrases more like Hamlet's). On average, the program re-created the phrase in just 336 iterations, less than 90 seconds. Even more amazing, it could reconstruct Shakespeare's entire play in just four and a half days.

9. The Second Law of Thermodynamics says that systems must become more disordered over time. Living cells therefore could not have evolved from inanimate chemicals, and multicellular life could not have evolved from protozoa.

This argument derives from a misunderstanding of the Second Law. If it were valid, mineral crystals and snowflakes would also be impossible, because they, too, are complex structures that form spontaneously from disordered parts.

The Second Law actually states that the total entropy of a closed system (one that no energy or matter leaves or enters) cannot decrease. Entropy is a physical concept often casually described as disorder, but it differs significantly from the conversational use of the word.

More important, however, the Second Law permits parts of a system to decrease in entropy as long as other parts experience an offsetting increase. Thus, our planet as a whole can grow more complex because the sun pours heat and light onto it, and the greater entropy associated with the sun's nuclear fusion more than rebalances the scales. Simple organisms can fuel their rise toward complexity by consuming other forms of life and nonliving materials.

10. Mutations are essential to evolution theory, but mutations can only eliminate traits. They cannot produce new features.

On the contrary, biology has catalogued many traits produced by point mutations (changes at precise positions in an organism's DNA)—bacterial resistance to antibiotics, for example.

Mutations that arise in the homeobox (*Hox*) family of development-regulating genes in animals can also have complex effects. *Hox* genes direct where legs, wings, antennae and body segments should grow. In fruit flies, for instance, the mutation called *Antennapedia* causes legs to sprout where antennae should grow. These abnormal limbs are not functional, but their existence demonstrates that genetic mistakes can produce complex structures, which natural selection can then test for possible uses.

Moreover, molecular biology has discovered mechanisms for genetic change that go beyond point mutations, and these expand the ways in which new traits can appear. Functional modules within genes can be spliced together in novel ways. Whole genes can be accidentally duplicated in an organism's DNA, and the duplicates are free to mutate into genes for new, complex features. Comparisons of the DNA from a wide variety of organisms indicate that this is how the globin family of blood proteins evolved over millions of years.

11. Natural selection might explain microevolution, but it cannot explain the origin of new species and higher orders of life.

Evolutionary biologists have written extensively about how

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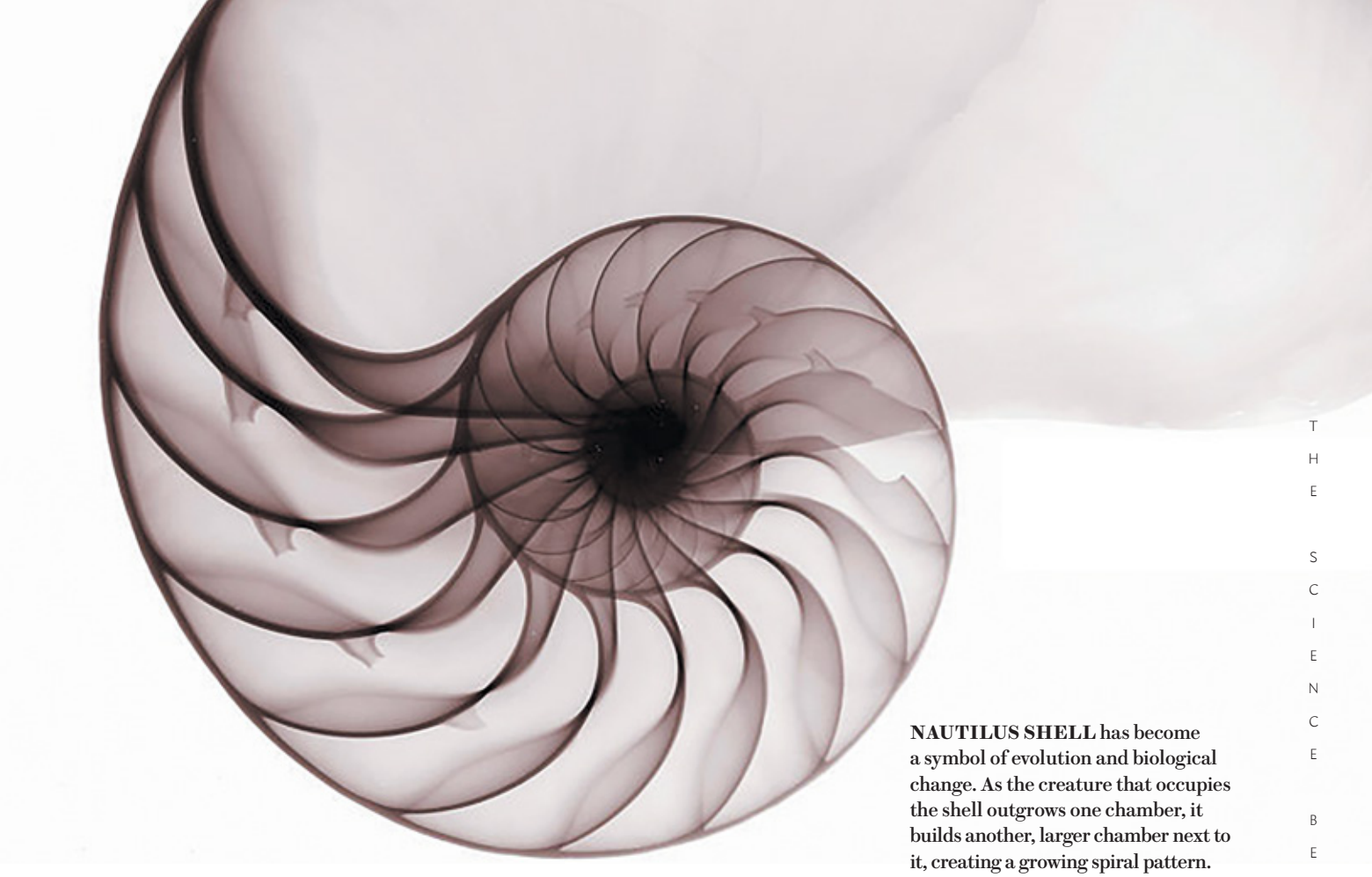

NAUTILUS SHELL has become a symbol of evolution and biological change. As the creature that occupies the shell outgrows one chamber, it builds another, larger chamber next to it, creating a growing spiral pattern.

BERT MEYERS Getty Images

natural selection could produce new species. For instance, in the model called allopatry, developed by Ernst Mayr of Harvard University, if a population of organisms were isolated from the rest of its species by geographical boundaries, it might be subjected to different selective pressures. Changes would accumulate in the isolated population. If those changes became so significant that the splinter group could not or routinely would not breed with the original stock, then the splinter group would be *reproductively isolated* and on its way toward becoming a new species.

Natural selection is the best studied of the evolutionary mechanisms, but biologists are open to other possibilities as well. Biologists are constantly assessing the potential of unusual genetic mechanisms for causing speciation or for producing complex features in organisms. Lynn Margulis of the University of Massachusetts Amherst and others have persuasively argued that some cellular organelles, such as the energy-generating mitochondria, evolved through the symbiotic merger of ancient organisms. Thus, science welcomes the possibility of evolution resulting from forces beyond natural selection. Yet those forces must be natural; they cannot be attributed to the actions of mysterious creative intelligences whose existence, in scientific terms, is unproved.

12. Nobody has ever seen a new species evolve.

Speciation is probably fairly rare and in many cases might take centuries. Furthermore, recognizing a new species during a formative stage can be difficult because biologists sometimes disagree about how best to define a species. The most widely used definition, Mayr's Biological Species Concept, recognizes a species as a distinct community of reproductively isolated populations—sets of organisms that normally do not or cannot breed outside their community. In practice, this standard can be difficult to apply to organisms isolated by distance or terrain or to plants (and, of course, fossils do not breed). Biologists therefore usually use organisms' physical and behavioral traits as clues to their species membership.

Nevertheless, the scientific literature does contain reports of apparent speciation events in plants, insects and worms. In most of these experiments, researchers subjected organisms to various types of selection—for anatomical differences, mating behaviors, habitat preferences and other traits—and found that they had created populations of organisms that did not breed with outsiders. For example, William R. Rice of the University of New Mexico and George W. Salt of the University of California, Davis, demonstrated that if they sorted a group of fruit flies by their preference for certain environments and bred those flies separately over 35 generations, the resulting flies would refuse to breed with those from a very different environment.

13. Evolutionists cannot point to any transitional fossils—creatures that are half reptile and half bird, for instance.

Actually, paleontologists know of many detailed examples of fossils intermediate in form between various taxonomic groups. One of the most famous fossils of all time is *Archaeopteryx,* which combines feathers and skeletal structures peculiar to birds with features of dinosaurs. A flock's worth of other feath-

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ered fossil species, some more avian and some less, has also been found. A sequence of fossils spans the evolution of modern horses from the tiny *Eohippus*. An amazing fossil creature from 375 million years ago named *Tiktaalik* embodies the predicted and long-sought transition of certain fishes to life on land. Whales had four-legged ancestors that walked on land, and creatures known as *Ambulocetus* and *Rodhocetus* helped to make that transition. Fossil seashells trace the evolution of various mollusks through millions of years. Perhaps 20 or more hominins (not all of them our ancestors) fill the gap between Lucy the australopithecine and modern humans.

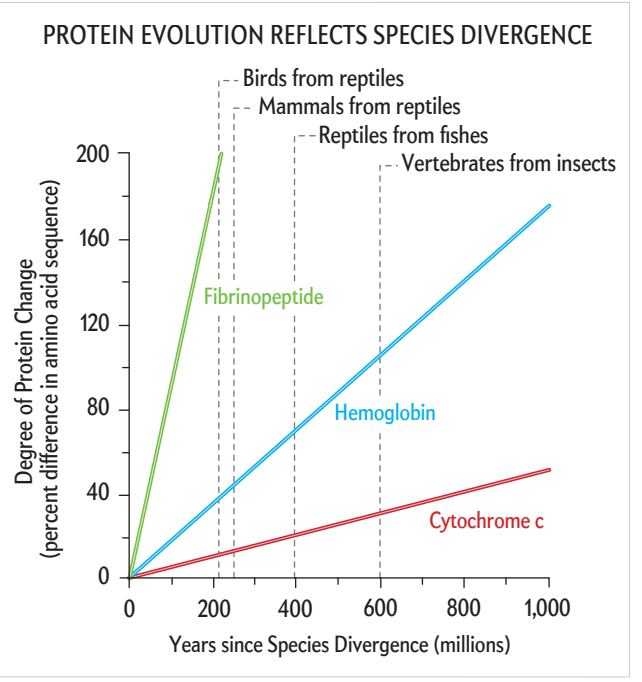
Creationists, though, dismiss these fossil studies. They argue that *Archaeopteryx* is not a missing link between reptiles and birds—it is just an extinct bird with reptilian features. They want evolutionists to produce a weird, chimeric monster that cannot be classified as belonging to any known group. Even if a creationist does accept a fossil as transitional between two species, he or she may then insist on seeing other fossils intermediate between it and the first two. These frustrating requests can proceed ad infinitum and place an unreasonable burden on the always incomplete fossil record.

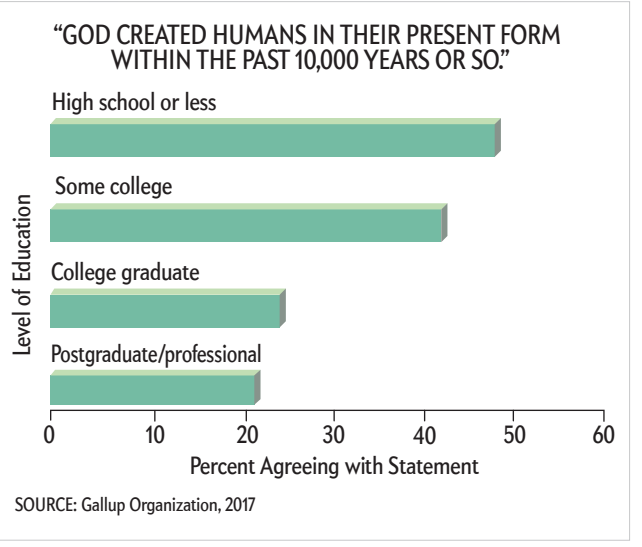
Nevertheless, evolutionists can cite further supportive evidence from molecular biology. All organisms share most of the same genes, but as evolution predicts, the structures of these genes and their products diverge among species, in keeping with their evolutionary relationships. Geneticists speak of the "molecular clock" that records the passage of time. These molecular data also show how various organisms are transitional within evolution.

14. Living things have fantastically intricate features—at the anatomical, cellular and molecular levels—that could not function if they were any less complex or sophisticated. The only prudent conclusion is that they are the products of intelligent design, not evolution.

This "argument from design" is the backbone of most recent attacks on evolution, but it is also one of the oldest. In 1802 theologian William Paley wrote that if one finds a pocket watch in a field, the most reasonable conclusion is that someone dropped it, not that natural forces created it there. By analogy, Paley argued, the complex structures of living things must be the handiwork of direct, divine invention. Darwin wrote *On the Origin of Species* as an answer to Paley: he explained how natural forces of selection, acting on inherited features, could gradually shape the evolution of ornate organic structures.

Generations of creationists have tried to counter Darwin by citing the example of the eye as a structure that could not have evolved. The eye's ability to provide vision depends on the perfect arrangement of its parts, these critics say. Natural selection could thus never favor the transitional forms needed during the eye's evolution—what good is half an eye? Anticipating this criticism, Darwin suggested that even "incomplete" eyes might confer benefits (such as helping creatures orient toward light) and thereby survive for further evolutionary refinement. Biology has vindicated Darwin: researchers have identified primitive eyes and light-sensing organs throughout the animal kingdom and have even tracked the evolutionary history of eyes through comparative genetics. (It now appears that in various families of organisms, eyes have evolved independently.)





Today's intelligent-design advocates are more sophisticated than their predecessors, but their arguments and goals are not fundamentally different. They criticize evolution by trying to demonstrate that it could not account for life as we know it and then insist that the only tenable alternative is that life was designed by an unidentified intelligence.

15. Recent discoveries prove that even at the microscopic level, life has a quality of complexity that could not have come about through evolution.

"Irreducible complexity" is the battle cry of Michael J. Behe of Lehigh University, author of *Darwin's Black Box: The Biochemical Challenge to Evolution*. As a household example of irreducible complexity, Behe chooses the mousetrap—a machine that could not function if any of its pieces were missing

CLEO VILLET

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Other Resources for Defending Evolution

How to Debate a Creationist: 25 Creationists' Arguments and 25 Evolutionists' Answers. Michael Shermer. Skeptics Society, 1997. This well-researched refutation of creationist claims deals in more depth with many of the same scientific arguments raised here, as well as other philosophical problems.

Skeptic magazine routinely covers creation/evolution debates and is a solid, thoughtful source on the subject: www.skeptic.com

Defending Evolution in the Classroom: A Guide to the Creation/Evolution Controversy. Brian J. Alters and Sandra M. Alters. Jones and Bartlett Publishers, 2001. This up-to-date overview of the creation/evolution controversy explores the issues clearly and readably, with a full appreciation of the cultural and religious influences that create resistance to teaching evolution. It, too, uses a question-and-answer format that should be particularly valuable for teachers.

Science and Creationism: A View from the National Academy of Sciences. Second edition. National Academy Press, 1999. This concise booklet has the backing of the country's top scientific authorities. Although its goal of making a clear, brief statement necessarily limits the detail with which it can pursue its arguments, the publication serves as handy proof that the scientific establishment unwaveringly supports evolution. It is also available via www.nap.edu/catalog

The Triumph of Evolution and the Failure of Creationism. Niles Eldredge. W. H. Freeman and Company, 2000. The author, a leading contributor to evolution theory and a curator at the American Museum of Natural History in New York City, offers a scathing critique of evolution's opponents.

Intelligent Design Creationism and Its Critics. Edited by Robert T. Pennock. Bradford Books/MIT Press, 2001. For anyone who wishes to understand the "intelligent design" controversy in detail, this book is a terrific one-volume summary of the scientific, philosophical and theological issues. Philip E. Johnson, Michael J. Behe and William A. Dembski make the case for intelligent design in their chapters and are rebutted by evolutionists, including Pennock, Stephen Jay Gould and Richard Dawkins.

Talk. Origins archive (www.talkorigins.org). This wonderfully thorough online resource compiles useful essays and commentaries that have appeared in Usenet discussions about creationism and evolution. It offers detailed discussions (some of which may be too sophisticated for casual readers) and bibliographies relating to virtually any objection to evolution that creationists might raise.

National Center for Science Education Web site (www.ncseweb.org). The center is the only national organization that specializes in defending the teaching of evolution against creationist attacks. Offering resources for combating misinformation and monitoring antievolution legislation, it is ideal for staying current with the ongoing public debate.

PBS Web site for evolution (www.pbs.org/wgbh/evolution). Produced as a companion to the seven-part television series *Evolution,* this site is an enjoyable guide to evolutionary science. It features multimedia tools for teaching evolution. The accompanying book, *Evolution*, by Carl Zimmer (HarperCollins, 2001), is also useful for explaining evolution to doubters.

and whose pieces have no value except as parts of the whole. What is true of the mousetrap, he says, is even truer of the bacterial flagellum, a whiplike cellular organelle used for propulsion that operates like an outboard motor. The proteins that make up a flagellum are uncannily arranged into motor components, a universal joint and other structures like those that a human engineer might specify. The possibility that this intricate array could have arisen through evolutionary modification is virtually nil, Behe argues, and that bespeaks intelligent design. He makes similar points about the blood's clotting mechanism and other molecular systems.

Yet evolutionary biologists have answers to these objections. First, there exist flagellae with forms simpler than the one that Behe cites, so it is not necessary for all those components to be present for a flagellum to work. The sophisticated components of this flagellum all have precedents elsewhere in nature, as described by Kenneth R. Miller of Brown University and others. In fact, the entire flagellum assembly is extremely similar to an organelle that *Yersinia pestis,* the bubonic plague bacterium, uses to inject toxins into cells.

The key is that the flagellum's component structures, which Behe suggests have no value apart from their role in propulsion, can serve multiple functions that would have helped favor their evolution. The final evolution of the flagellum might then have involved only the novel recombination of sophisticated parts that initially evolved for other purposes. Similarly, the blood-clotting system seems to involve the modification and elaboration of proteins that were originally used in digestion, according to studies by Russell F. Doolittle of the University of California, San Diego. So some of the complexity that Behe calls proof of intelligent design is not irreducible at all.

Complexity of a different kind—"specified complexity"—is the cornerstone of the intelligent-design arguments of author William A. Dembski in his books *The Design Inference* and *No Free Lunch*. Essentially his argument is that living things are complex in a way that undirected, random processes could never produce. The only logical conclusion, Dembski asserts, in an echo of Paley 200 years ago, is that some superhuman intelligence created and shaped life.

Dembski's argument contains several holes. It is wrong to insinuate that the field of explanations consists only of random processes or designing intelligences. Researchers into nonlinear systems and cellular automata at the Santa Fe Institute and elsewhere have demonstrated that simple, undirected processes can yield extraordinarily complex patterns. Some of the complexity seen in organisms may therefore emerge through natural phenomena that we as yet barely understand. But that is far different from saying that the complexity could not have arisen naturally. SA

John Rennie is the former editor in chief of *Scientific American.*

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50 YEARS AGO:

REPEAL OF TENNESSEE'S "MONKEY LAW"

The statute that got John Scopes in trouble was finally repealed in 1967—but the teaching of evolution in public schools is still not entirely safe

By Glenn Branch and Ann Reid

Illustration by Scott Brundage

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GARY SCOTT HADN'T REALIZED THAT HE WASN'T SUPPOSED TO TEACH evolution. But on April 13, 1967, the young Jacksboro, Tenn., science teacher was fired for violating section 49-1922 of the Tennessee Code—the so-called Butler Act, also known as the "Monkey Law," under which a different young science teacher in Tennessee was indicted, prosecuted and convicted 42 years earlier, in *The State of Tennessee v. John Thomas Scopes*. Thanks in part to a legal challenge filed by Scott to the constitutionality of the Butler Act, the Tennessee legislature decided to repeal the law, and the governor signed the repeal measure on May 18, 1967. Shortly thereafter, the remaining state bans on the teaching of evolution—in Arkansas and Mississippi—were ruled to be unconstitutional in the courts.

Half a century later, though, the schools are still not entirely safe for evolution.

From Scopes through Scott to today, science teachers have been in the trenches of the evolution wars, bearing the brunt of conflicting forces from science and society. In science, evolution is universally accepted on the basis of overwhelming evidence from diverse lines of inquiry. In society, however, it is often regarded with suspicion, arising mainly from a view that evolution conflicts with the creation accounts of the Bible.

The magnitude of the disconnection between science and society is suggested by a survey conducted by the Pew Research Center in 2014, according to which 98 percent of American scientists accepted evolution, but only 62 percent of the American general public agreed, with 34 percent preferring a creationist alternative—"Humans have existed in their present form since the beginning of time"—instead.

Not all of those 31 percent vehemently deny evolution, to be sure. Surveys that allow respondents to indicate their level of confidence in their answers or that add "don't know" and "not sure" as possible answers reveal substantial ambivalence and uncertainty in public opinion on evolution, with relatively few ardent creationists. But in a climate of doubt, denial is able to exert disproportionate influence.

JOHN SCOPES, subject of the famous "monkey trial."

Prompted by fundamentalist religious attitudes, doubt and denial about evolution motivated the passage of the Butler Act in Tennessee in 1925. They have not disappeared in the 50 years since its repeal. The strategies used to launch attacks on the teaching of evolution in the public schools have mutated, however, striving to adapt to shifting legal, political and educational landscapes.

When banning the teaching of evolution failed as a strategy, evolution's opponents were forced to take a different approach: calling for the teaching of a supposed alternative to evolution for the sake of balance. The alternatives—biblical creationism, creation science, intelligent design—were advanced with increasingly determined attempts to conceal their religious basis in the hope that they would survive the scrutiny of the courts.

But these alternatives were found to be unconstitutional at every turn. A Tennessee state law requiring textbooks to include

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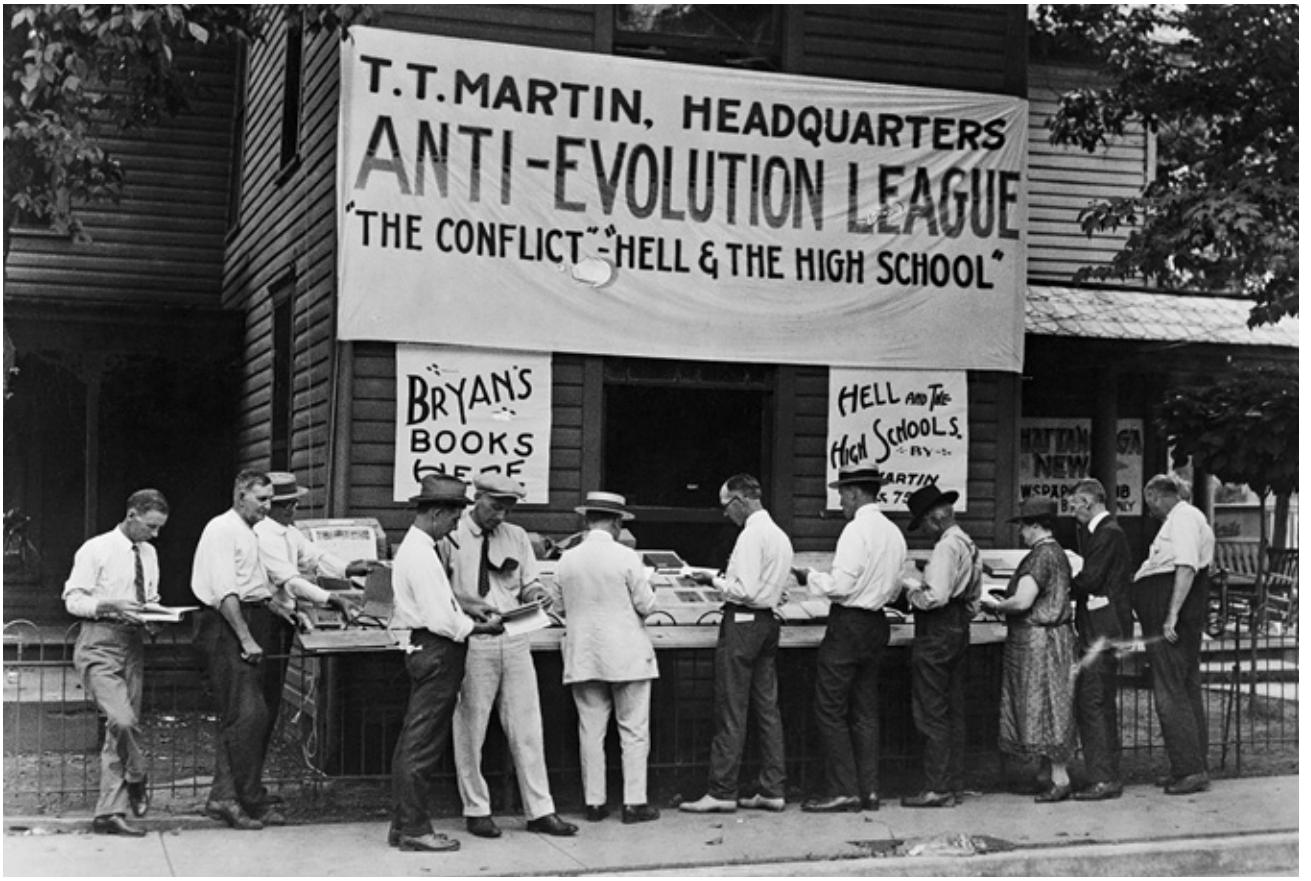

BOOK SALE put on by the Anti-Evolution League at the opening of the Scopes "Monkey Trial" in Dayton, Tenn.

biblical creationism was struck down in 1975; Arkansas and Louisiana state laws requiring balancing evolution with creation science were struck down in 1982 and 1987; and a Pennsylvania school district's policy requiring the presentation of intelligent design was struck down in 2005.

Even before the legal defeat of intelligent design in Pennsylvania, evolution's opponents were already beginning to try yet a different tack: requiring, or more commonly allowing, science teachers to misrepresent evolution as scientifically controversial, often under the rubric of academic freedom. More than 70 such bills have been introduced since 2004, with three enacted, in Mississippi, Louisiana and Tennessee.

It is unclear to what extent science teachers in those three states take advantage of those laws. But according to a national survey conducted in 2007, about one in eight public high school biology teachers present creationism as scientifically credible in their classrooms, despite the unconstitutionality of the practice. Scientific, educational and legal concerns are often overridden by personal or community attitudes of doubt and denial.

Indeed, the same survey revealed that six in 10 of the instructors were teaching evolution less than forthrightly—compromising on the accuracy, completeness or rigor of their treatment, often for fear of provoking a creationist backlash. Such fears, sadly, appear to be warranted: more than one in five of the teachers reported experiencing community resistance to their teaching of evolution.

Fortunately, the treatment of evolution in state science standards is getting better on the whole, which means that textbooks, curricula and, ideally, teachers are following suit. But scientific knowledge and pedagogical know-how are not the only equipment that educators need to teach evolution. They also need the confidence to persist, even in the face of doubt and denial.

Creationists are as active as ever, with a few even in the bully pulpits afforded by high political office. And the legal rulings that established the obstacles that have so far thwarted attacks on evolution education could be overturned by a reactionary Supreme Court or circumvented by public support of religious schools not subject to constitutional strictures. So the evolution wars are by no means over.

Gary Scott's own service in the evolution wars was for just a brief skirmish: he was reinstated—with back pay—at Jacksboro High School even before the Butler Act was repealed. He wasn't the last science teacher to play the role of hero in the contentious history of evolution education in the U.S. But science teachers shouldn't have to engage in heroics to present evolution forthrightly, without fear and beyond reproach. SA

Glenn Branch is deputy director of the National Center for Science Education, a nonprofit organization that defends the integrity of science education against ideological interference.

Ann Reid is executive director of the National Center for Science Education.

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SHOULD SCIENCE SPEAK TO FAITH?

Two prominent defenders of science exchange their views on how scientists ought to approach religion and its followers

By Lawrence M. Krauss and Richard Dawkins

Introduction

Although the authors are both on the side of science, they have not always agreed about the best ways to oppose religiously motivated threats to scientific practice or instruction. Krauss, a leading physicist, frequently steps into the public spotlight to argue in favor of retaining evolutionary theory in school science curricula and keeping pseudoscientific variants of creationism out of them. An open letter he sent to Pope Benedict XVI in 2005, urging the pontiff not to build new walls between science and faith, led the Vatican to reaffirm the Catholic Church's acceptance of natural selection as a valid scientific theory.

Dawkins, an evolutionary biologist, prolific author and lecturer, is also an eloquent critic of any attempt to undermine scientific reasoning. He has generally shown less interest than Krauss, however, in achieving a peaceful coexistence between science and faith. The title of Dawkins's best-selling 2006 book *The God Delusion* perhaps best summarizes his opinion of religious belief.

These two allies compared notes from the front lines during breaks at a conference devoted to discussing clashes between science and religion held at the Salk Institute for Biological Studies in San Diego in 2006. In a dialogue they re-create here, the authors explained their respective tactics for engaging the enemy and tackled some of the questions that face all scientists when deciding whether and how to talk to the faithful about science: Is the goal to teach science or to discredit religion? Can the two worldviews ever enrich each other? Is religion inherently bad? *—The Editors*

Illustration by Matt Collins

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Krauss: Both you and I have devoted a substantial fraction of our time to trying to get people excited about science, while also attempting to explain the basis of our current respective scientific understandings of the universe. So it seems appropriate to ask what the primary goals of a scientist should be when talking or writing about religion. I wonder which is more important: using the contrast between science and religion to teach about science or trying to put religion in its place? I suspect that I want to concentrate more on the first issue, and you want to concentrate more on the second.

I say this because if one is looking to teach people, then it seems clear to me that one needs to reach out to them, to understand where they are coming from, if one is going to seduce them into thinking about science. I often tell teachers, for example, that the biggest mistake any of them can make is to assume that their students are interested in what they are about to say. Teaching *is* seduction. Telling people, on the other hand, that their deepest beliefs are simply silly—even if they *are*—and that they should therefore listen to us to learn the truth ultimately defeats subsequent pedagogy. Having said that, if instead the primary purpose in discussing this subject is to put religion in its proper context, then perhaps it is useful to shock people into questioning their beliefs.

Dawkins: The fact that I think religion is bad science, whereas you think it is ancillary to science, is bound to bias us in at least slightly different directions. I agree with you that teaching is seduction, and it could well be bad strategy to alienate your audience before you even start. Maybe I could improve my seduction technique. But nobody admires a dishonest seducer, and I wonder how far you are prepared to go in "reaching out." Presumably you wouldn't reach out to a Flat Earther. Nor, perhaps, to a Young Earth Creationist who thinks the entire universe began after the Middle Stone Age. But perhaps you would reach out to an Old Earth Creationist who thinks God started the whole thing off and then intervened from time to time to help evolution over the difficult jumps. The difference between us is quantitative, only. You are prepared to reach out a little further than I am, but I suspect not all that much further.

LK: Let me make clearer what I mean by reaching out. I do not mean capitulating to misconceptions but rather finding a seductive way to demonstrate to people that these are indeed misconceptions. Let me give you one example. I have, on occasion, debated both creationists and alien abduction zealots. Both groups have similar misconceptions about the nature of explanation: they feel that unless you understand everything, you understand nothing. In debates, they pick some obscure claim, say, that in 1962 some set of people in Outer Mongolia all saw a flying saucer hovering above a church. Then they ask if I am familiar with this particular episode, and if I say no, they invariably say, "If you have not studied every such episode, then you cannot argue that alien abduction is unlikely to be happening."

I have found that I can get each group to think about what they are saying by using the other group as a foil. Namely, of the creationists I ask, "Do you believe in flying saucers?" They inevitably say "no." Then I ask, "Why? Have you studied all of the claims?" Similarly, to the alien abduction people I ask, "Do you believe in Young Earth Creationism?" and they say "no," wanting to appear scientific. Then I ask, "Why? Have you studied every single counterclaim?" The point I try to make for each group is that it is quite sensible to base theoretical expectations on a huge quantity of existing evidence, without having studied absolutely every single obscure counterclaim. This "teaching" technique has worked in most cases, except those rare times when it has turned out that I was debating an alien abduction believer who was also a creationist!

RD: I like your clarification of what you mean by reaching out. But let me warn you of how easy it is to be misunderstood. I once wrote in a *New York Times* book review, "It is absolutely safe to say that if you meet somebody who claims not to believe in evolution, that person is ignorant, stupid or insane (or wicked, but I'd rather not consider that)." That sentence has been quoted again and again in support of the view that I am a bigoted, intolerant, closed-minded, intemperate ranter. But just look at my sentence. It may not be crafted to seduce, but you, Lawrence, know in your heart that it is a simple and sober statement of fact.

Ignorance is no crime. To call somebody ignorant is no insult. All of us are ignorant of most of what there is to know. I am completely ignorant of baseball, and I dare say that you are as completely ignorant of cricket. If I tell somebody who believes the world is 6,000 years old that he is ignorant, I am paying him the compliment of assuming that he is not stupid, insane or wicked.

LK: I have to say that I agree completely with you about this. To me, ignorance is often the problem, and, happily, ignorance is most easily addressed. It is not pejorative to suggest that someone is ignorant if they misunderstand scientific issues.

RD: In exchange, I am happy to agree with you that I could, and probably should, have put it more tactfully. I should have reached out more seductively. But there are limits. You would stop short of the following extreme: "Dear Young Earth Creationist, I deeply respect your belief that

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Richard Dawkins was Charles Simonyi Professor of the Public Understanding of Science at the University of Oxford from 1995 to 2008. His nine books have earned him honorary doctorates in literature and science, and he is a Fellow of both the Royal Society and the Royal Society of Literature. His many prizes include the Cosmos International Prize, the Nakayama Prize for Human Science and the Shakespeare Prize for Distinguished Contributions to British Culture. In 2006 he created the Richard Dawkins Foundation for Reason and Science. New British school guidelines encourage students to play the roles of such figures as Galileo, Darwin and Dawkins while debating science and creationism. He serves on *Scientific American*'s board of advisers.

WIN MCNAMEE *Getty Images (Krauss)*; DAVID LEVENSON *Getty Images (Dawkins)*

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the world is 6,000 years old. Nevertheless, I humbly and gently suggest that if you were to read a book on geology, or radioisotope dating, or cosmology, or archaeology, or history, or zoology, you might find it fascinating (along with the Bible, of course), and you might begin to see why almost all educated people, including theologians, think the world's age is measured in billions of years, not thousands."

Let me propose an alternative seduction strategy. Instead of pretending to respect dopey opinions, how about a little tough love? Dramatize to the Young Earth Creationist the sheer magnitude of the discrepancy between his beliefs and those of scientists: "6,000 years is not just a little bit different from 4.6 billion years. It is so different that, dear Young Earth Creationist, it is as though you were to claim that the distance from New York to San Francisco is not 3,400 miles but 7.8 yards. Of course, I respect your right to disagree with scientists, but perhaps it wouldn't hurt and offend you too much to be told—as a matter of deductive and indisputable arithmetic—the actual magnitude of the disagreement you've taken on."

LK: I don't think your suggestion is "tough love." In fact, it is precisely what I was advocating, namely, a creative and seductive way of driving home the magnitude and nature of such misconceptions. Some people will always remain deluded, in spite of facts, but surely those are not the ones we are trying to reach. Rather it is the vast bulk of the public who may have open minds about science but simply don't know much about it or have never been exposed to scientific evidence. In this regard, let me pose another question, about which you may feel even more strongly: Can science enrich faith, or must it always destroy it?

The question came to me because I was recently asked to speak at a Catholic college at a symposium on science and religion. I guess I was viewed as someone interested in reconciling the two. After agreeing to lecture, I discovered that I had been assigned the title Science Enriching Faith. In spite of my initial qualms, the more I thought about the title, the more rationale I could see for it. The need to believe in a divine intelligence without direct evidence is, for better or worse, a fundamental component of many people's psyches. I do not think we will rid humanity of religious faith any more than we will rid humanity of romantic love or many of the irrational but fundamental aspects of human cognition. While orthogonal from the scientific rational components, they are no less real and perhaps no less worthy of some celebration when we consider our humanity.

RD: As an aside, such pessimism about humanity is popular among rationalists to the point of outright masochism. It is almost as though you and others at the conference where this dialogue began positively relish the idea that humanity is perpetually doomed to unreason. But I think irrationality has nothing to do with romantic love or poetry or the emotions that lie so close to what makes life worth living. Those are not orthogonal to rationality. Perhaps they are tangential to it. In any case, I am all for them, as are you. Positively irrational beliefs and superstitions are a different matter entirely. To accept that we can never be rid of them—that they are an irrevocable part of human nature—is manifestly untrue of you and, I would guess, most of your colleagues and friends. Isn't it therefore rather condescending to assume that humans at large are constitutionally incapable of breaking free of them?

LK: I am not so confident that I am rid of irrational beliefs, at least irrational beliefs about myself. But if religious faith is a central part of the life experience of many people, the question, it seems to me, is not how we can rid the world of God but to what extent can science at least moderate this belief and cut out the most irrational and harmful aspects of religious fundamentalism. That is certainly one way science might enrich faith.

In my lecture to the Catholic group, for instance, I took guidance from your latest book and described how scientific principles, including the requirement not to be selective in choosing data, dictate that one cannot pick and choose in one's fundamentalism. If one believes that homosexuality is an abomination because it says so in the Bible, one has to accept the other things that are said in the Bible, including the allowance to kill your children if they are disobedient or validation of the right to sleep with your father if you need to have a child and there are no other men around, and so forth.

Moreover, science can directly debunk many such destructive literal interpretations of Scripture, including, for example, the notion that women are simple chattels, which stands counter to what biology tells us about the generic biological roles of females and the intellectual capabilities of women and men in particular. In the same sense that Galileo argued, when he suggested that God would not have given humans brains if "he" did not intend people to use them to study nature, science definitely can thus enrich faith.

Still another benefit science has to offer was presented most cogently by Carl Sagan, who, like you and me, was not a person of faith. Nevertheless, in a posthumous compilation of his 1985 Gifford Lectures in Scotland on science and religion, he makes the point that standard religious wonder is in fact too myopic, too limited. A single world is too puny for a real God. The vast scope of our universe, revealed to us by science, is far grander. Moreover, one might now add, in light of the current vogue in theoretical physics, that a single universe may be too puny and that one might want to start thinking in terms of a host of universes. I hasten to add, however, that enriching faith is far different than providing supporting evidence for faith, which is something that I believe science certainly does not do.

RD: Yes, I love that sentiment of Sagan's, and I'm so glad you picked it out. I summed it up for the publishers of those lectures on the book jacket: "Was Carl Sagan a religious man? He was so much more. He left behind the petty, parochial, medieval world of the conventionally religious; left the theologians, priests and mullahs wallowing in their small-minded spiritual poverty. He left them behind because he had so much more to be religious about. They have their Bronze Age myths, medieval superstitions and childish wishful thinking. He had the universe." I don't think there is anything I can add in answering your question about whether science can enrich faith. It can, in the sense you and Sagan mean. But I'd hate to be misunderstood as endorsing faith.

LK: I want to close with an issue that I think is central to much of the current debate going on among scientists regarding religion: Is religion inherently bad? I confess here that my own views have evolved over the years, although you might argue that I have simply gone soft. There is certainly ample evidence that religion has

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been responsible for many atrocities, and I have often said, as have you, that no one would fly planes into tall buildings on purpose if it were not for a belief that God was on their side.

As a scientist, I feel that my role is to object when religious belief causes people to teach lies about the world. In this regard, I would argue that one should respect religious sensibilities no more or less than any other metaphysical inclinations, but in particular they should not be respected when they are wrong. By wrong, I mean beliefs that are manifestly in disagreement with empirical evidence. The earth is not 6,000 years old. The sun did not stand still in the sky. What we need to try to eradicate is not religious belief, or faith, it is ignorance. Only when faith is threatened by knowledge does it become the enemy.

RD: I think we pretty much agree here. And although "lie" is too strong a word because it implies intention to deceive, I am not one of those who elevate moral arguments above the question of whether religious beliefs are true. When I had a televised encounter with the veteran British politician Tony [the late Anthony Wedgwood] Benn, a former minister of technology who calls himself a Christian. It became very clear in the course of our discussion that he had not the slightest interest in whether Christian beliefs are true or not; his only concern was whether they are moral. He objected to science on the grounds that it gave no moral guidance. When I protested that moral guidance is not what science is about, he came close to asking what, then, was the use of science. A classic example of a syndrome the philosopher Daniel Dennett has called "belief in belief."

Other examples include those people who think that whether religious beliefs are true or false is less important than the power of religion to comfort and to give a purpose to life. I imagine you would agree with me that we have no objection to people drawing comfort from wherever they choose and no objection to strong moral compasses. But the question of the moral or consolation value of religion—one way or the other—must be kept separate in our minds from the truth value of religion. I regularly encounter difficulties in persuading religious people of this distinction, which suggests to me that we scientific seducers have an uphill struggle on our hands. SA

Notes from the Authors

Krauss: In the 10 years since Richard and I participated in the writing of this piece, I confess that my own ideas have evolved considerably. After writing my book *A Universe from Nothing* (for which Richard wrote the afterword), and then making a film with Richard called *The Unbelievers,* and after meeting many people who have conveyed their religious experiences, I have come around to the realization that religion is nowhere near as innocuous as I imagined in 2007. In particular, far too many people, many in small towns with no like-minded people to talk to, feel they are immoral for merely asking questions about the existence of God. They also feel alone, or strange, and do not realize that people all around them are feeling the same thing. That is one of the virtues and necessities of speaking out loudly against religion, so that people realize that it is okay to do so. We should encourage questioning of everything. Nothing should be sacred. And in particular, as Richard referred to above, many people call themselves Christians, not with an iota of concern about the reality of the Scriptures, but rather because they want to think of themselves as good people. (Indeed, Richard's foundation confirmed this with a survey they did several years ago in the U.K.) Although that is understandable, we need to break this monopoly on morality, where not believing in God identifies you as immoral. A recent study by a group of Canadian and American psychologists discovered that atheists are on par with rapists as the least trusted group by adults in those countries. We need to work hard to ensure that atheism is not a dirty word and that choosing not to believe in fairy tales doesn't diminish you as a human being. Rather it should elevate you. And finally, perhaps influenced by neuroscientist and religion skeptic Sam Harris over the years, I also am unwilling now to accept in any way that science is consistent with the beliefs of the world's major religions.

It is true that science isn't incompatible with a vague and rather impotent God who has never revealed any supernatural handiwork after supposedly creating the universe. But that is not the God of the Scriptures. And scientists who fear that saying this will somehow alienate those who currently fear science as an atheistic enterprise are being hypocrites. They wouldn't hesitate to attack astrology on similar grounds, for example.

Dawkins: I agree with everything Lawrence says in his afterword. With one small exception. I don't think science is compatible even with "a vague and rather impotent God who has never revealed any supernatural handiwork after supposedly creating the universe." Most certainly, I agree that "that is not the God of the Scriptures." Confusing the two is one of the more dishonest tricks played by "sophisticated theologians." But even the deist god who does nothing after the moment of creation is incompatible with science. In order to create the universe and craft the laws of physics so that they will eventually give rise to coalescing galaxies and stars, chemistry and eventually life, the deist god cannot be vague and impotent. He would have to be a mathematical and scientific genius, an object of prodigious complexity of exactly the kind that needs a scientific explanation in its own right. Entities complex enough to design anything come late into the universe, as the end products of long evolutionary progressions from simple beginnings.

I would amend Lawrence's conclusion, replacing his impotent deist god by an even more impotent pantheist god, Spinoza's god, the god of Einstein.

MORE TO EXPLORE

Unweaving the Rainbow: Science, Delusion and the Appetite for Wonder. Richard Dawkins. Houghton Mifflin, 1998.
Questions That Plague Physics. Lawrence M. Krauss and Claudia Driefus in *Scientific American,* Vol. 291, No. 2, pages 82–85; August 2004.
The God Delusion. Richard Dawkins. Houghton Mifflin, 2006.
Hiding in the Mirror: The Quest for Alternate Realities, from Plato to String Theory. L. M. Krauss. Penguin, 2006.
Beyond Belief: Science, Religion, Reason and Survival. Conference videos and background at http://thesciencenetwork.org/programgroup/beyond-belief
The official Richard Dawkins Web site: http://richarddawkins.net
Lawrence M. Krauss's home page: www.phys.cwru.edu/~krauss

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END NOTE

When Facts Backfire

Why worldview threats undermine evidence

By Michael Shermer

HAVE YOU EVER NOTICED that when you present people with facts that are contrary to their deepest held beliefs they always change their minds? Me neither. In fact, people seem to double down on their beliefs in the teeth of overwhelming evidence against them. The reason is related to the worldview perceived to be under threat by the conflicting data.

Creationists, for example, dispute the evidence for evolution in fossils and DNA because they are concerned about secular forces encroaching on religious faith. Antivaxxers distrust big pharma and think that money corrupts medicine, which leads them to believe that vaccines cause autism despite the inconvenient truth that the one and only study claiming such a link was retracted and its lead author accused of fraud. The 9/11 truthers focus on minutiae like the melting point of steel in the World Trade Center buildings that caused their collapse because they think the government lies and conducts "false flag" operations to create a New World Order. Climate deniers study tree rings, ice cores and the ppm of greenhouse gases because they are passionate about freedom, especially that of markets and industries to operate unencumbered by restrictive government regulations. Obama birthers desperately dissected the president's long-form birth certificate in search of fraud because they believe that the nation's first African-American president is a socialist bent on destroying the country.

IF CORRECTIVE FACTS ONLY MAKE MATTERS WORSE, WHAT CAN WE DO TO CONVINCE PEOPLE OF THE ERROR OF THEIR BELIEFS?

In these examples, proponents' deepest held worldviews were perceived to be threatened by skeptics, making facts the enemy to be slayed. This power of belief over evidence is the result of two factors: cognitive dissonance and the backfire effect. In the classic 1956 book *When Prophecy Fails,* psychologist Leon Festinger and his co-authors described what happened to a UFO cult when the mother ship failed to arrive at the appointed time. Instead of admitting error, "members of the group sought frantically to convince the world of their beliefs," and they made "a series of desperate attempts to erase their rankling dissonance by making prediction after prediction in the hope that one would come true." Festinger called this cognitive dissonance, or the uncomfortable tension that comes from holding two conflicting thoughts simultaneously.

In their 2007 book *Mistakes Were Made (But Not by Me),* two social psychologists, Carol Tavris and Elliot Aronson (a former student of Festinger), document thousands of experiments demonstrating how people spin-doctor facts to fit preconceived beliefs to reduce dissonance. Their metaphor of the "pyramid of choice" places two individuals side by side at the apex of the pyramid and shows how quickly they diverge and end up at the bottom opposite corners of the base as they each stake out a position to defend.

In a series of experiments by Dartmouth College professor Brendan Nyhan and University of Exeter professor Jason Reifler, the researchers identify a related factor they call the backfire effect "in which corrections actually *increase* misperceptions among the group in question." Why? "Because it threatens their worldview or self-concept." For example, subjects were given fake newspaper articles that confirmed widespread misconceptions, such as that there were weapons of mass destruction in Iraq. When subjects were then given a corrective article that WMD were never found, liberals who opposed the war accepted the new article and rejected the old, whereas conservatives who supported the war did the opposite … and more: they reported being even *more* convinced there were WMD after the correction, arguing that this only proved that Saddam Hussein hid or destroyed them. In fact, Nyhan and Reifler note, among many conservatives "the belief that Iraq possessed WMD immediately before the U.S. invasion persisted long after the Bush administration itself concluded otherwise."

If corrective facts only make matters worse, what can we do to convince people of the error of their beliefs? From my experience, **1** keep emotions out of the exchange, **2** discuss, don't attack (no ad hominem and no ad Hitlerum), **3** listen carefully and try to articulate the other position accurately, **4** show respect, **5** acknowledge that you understand why someone might hold that opinion, and **6** try to show how changing facts does not necessarily mean changing worldviews. These strategies may not always work to change people's minds, but now that the nation has just been put through a political fact-check wringer, they may help reduce unnecessary divisiveness. SA

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His latest book is *Heavens on Earth* (Henry Holt, 2018). Follow him on Twitter @michaelshermer

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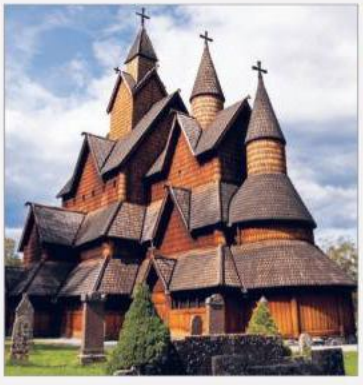

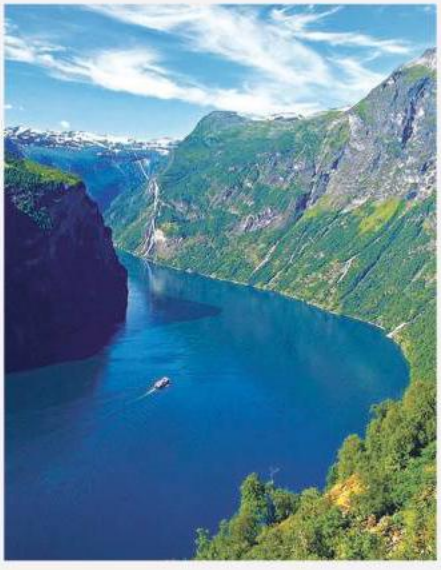

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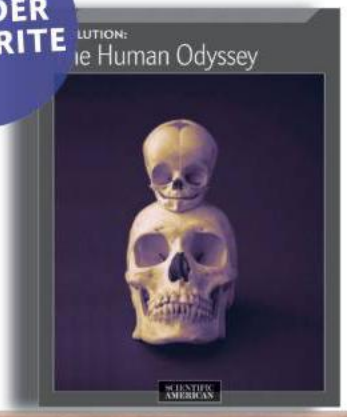

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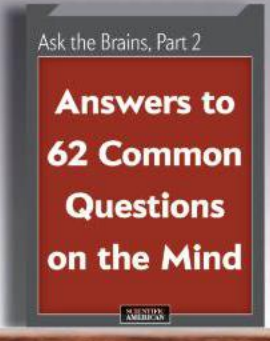
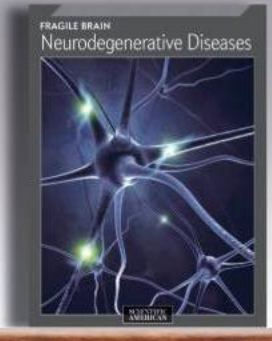
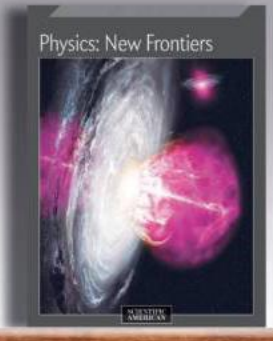
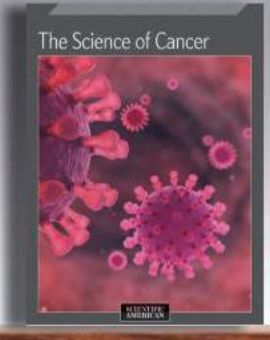
The Human Odyssey

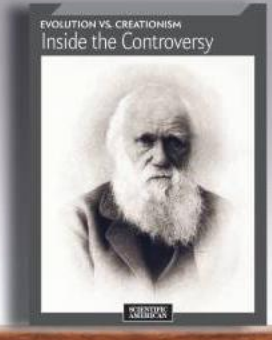
The story of how humanity came to be is a tale seven million years in the making and, like us, is still evolving. This eBook examines a spate of recent discoveries and how they've extended – or rewritten – our understanding of how certain traits arose, factors that helped our survival and characteristics that set us up to thrive.

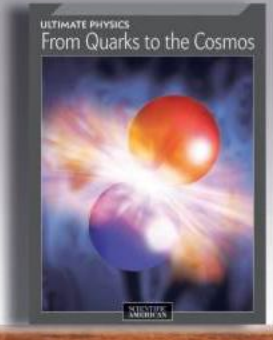












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The More to Explore section of "Should Science Speak to Faith?" by Lawrence M. Krauss and Richard Dawkins, gives an outdated home page for Krauss. His current Web site is at http://krauss.faculty.asu.edu.